SPACELAB 2

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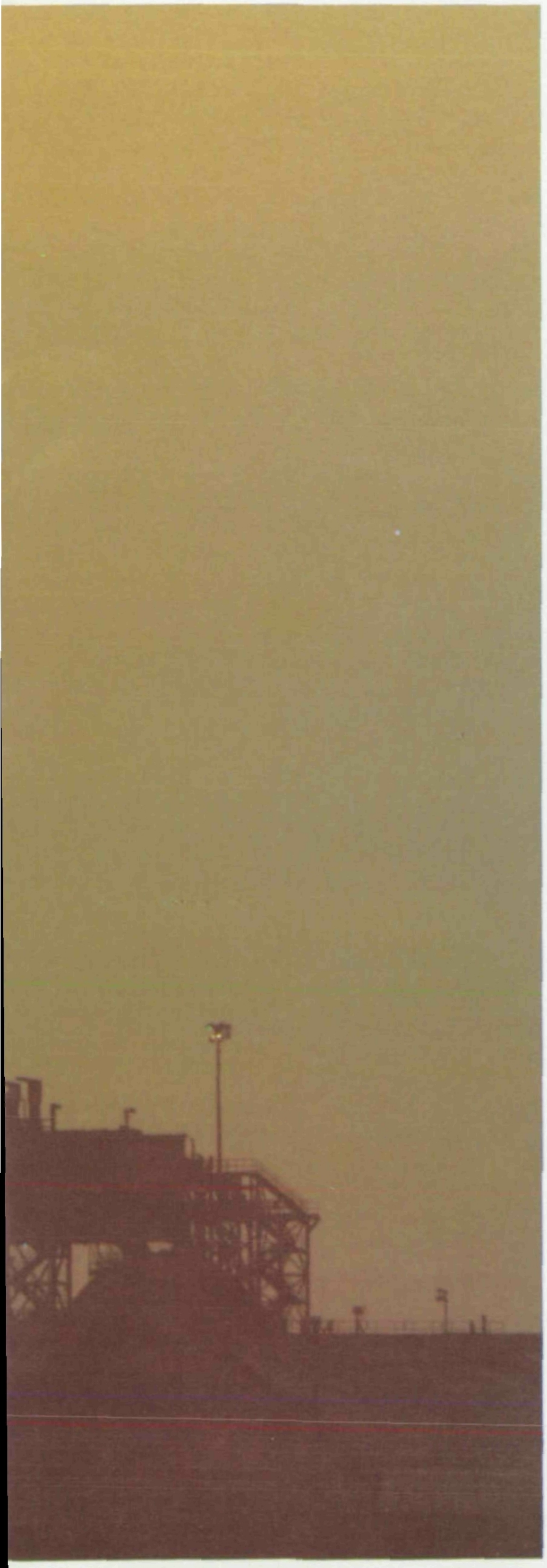


SPACE AS A LABORATORY

Today scientists are working in a remarkable new laboratory: *space*. Here they can look more clearly at the sun and stars, probe the gases that envelop Earth, and examine materials and living organisms beyond the influence of Earth's gravity. They are using new tools and techniques that provide dramatically improved access to the remote, minute, and invisible details of nature. Such technological advances enhance the power of human observation and lead to discovery.

The most promising new technology for scientific research is America's Space Transportation System—the Space Shuttle and its companion facility, Spacelab. Spacelab is a versatile laboratory designed specifically to accommodate scientists and their instruments in low-Earth orbit. In a space laboratory, scientists can perform experiments that are impossible on Earth. They can also use very large instruments aboard the Shuttle, with the added benefit of bringing all their equipment, experiment samples, and data home for analysis.

Spacelab 2 is one in a series of missions that gives the world's scientists a chance to do research in a well-equipped laboratory in space. The Spacelab 2 scientists have spent years in laboratories on the ground making observations, experimenting, and developing high-precision instruments. They have placed instruments on balloons, airplanes, rockets, and satellites, but in those investigations they never had the direct "hands-on" experiment control that Spacelab offers.

Spacelab represents a new phase in the evolution of science: the regular use of space as a suitable environment for manned laboratory research. This trend will continue as scientists equip laboratories aboard orbital platforms and space stations. Major scientific and technological advances are expected as habitable research facilities become permanent fixtures in space. ■

MISSION SCENARIO

The Spacelab 2 mission begins with a launch from Kennedy Space Center in mid-1985. Inside the orbiter Challenger, Spacelab 2 circles the globe at an altitude of approximately 390 kilometers (242 miles) and an inclination of 49.5° to the equator. During the seven-day mission, the National Aeronautics and Space Administration (NASA) plans to further verify the performance of Spacelab as a new research facility and to obtain scientific data from several ingenious experiments.

Spacelab is a versatile laboratory developed for NASA by the European Space Agency (ESA). Beginning with the Spacelab 1 mission in 1983, Spacelab has been used for research in various fields of science. Spacelab 2 continues this tradition with 13 investigations in 7 scientific disciplines: solar physics, atmospheric physics, plasma physics, high-energy astrophysics, infrared astronomy, technology research, and life sciences. Some of these research areas overlap, and several of the instruments work together to study the same phenomena with different techniques.

Each Spacelab mission has a unique design appropriate to the mission's goals. A number of Spacelab configurations can be assembled from various standardized parts, such as habitable modules, an igloo, and exposed platforms called pallets. Three pallets, an Instrument Pointing System, and a special support structure are the main Spacelab 2 components.

Spacelab 2 is the first pallet-only mission. One of the goals of the mission is to verify that the pallet configuration is satisfactory for observations and research. Except for two biological experiments and an experiment that uses ground-based instruments, the Spacelab 2 scientific instruments need direct exposure to space. From this vantage point, they can view the sun and celestial objects and study the space environment near the Shuttle.

On the first pallet, three solar instruments and one atmospheric instrument are mounted on the Instrument Pointing System, which is being tested on its first flight. ESA developed this innovative pointing system for the Spacelab program. Previously, instruments were pointed toward particular celestial objects or areas by maneuvering the Shuttle to an appropriate attitude. The Instrument Pointing System can aim instruments more accurately than the Shuttle does and keep them fixed on a target as the Shuttle moves. One plasma physics instrument, an electron beam generator, is also mounted on the first pallet.

The second Spacelab pallet holds a large double X-ray telescope and three plasma physics detectors. The last pallet supports an infrared telescope, a superfluid helium technology experiment, and a small plasma diagnostics satellite. At the aft end of the pallet train, a huge, egg-shaped cosmic ray detector

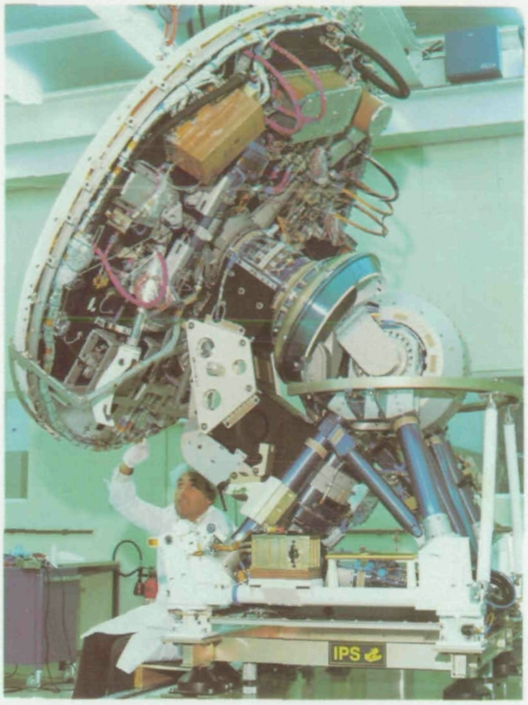
is mounted in a specially designed support structure that is tilted to increase detector exposure to space.

Another component, the igloo, houses Spacelab subsystems for computer operations, data transmission, and thermal control. This cylindrical, pressurized container is located directly outside the Shuttle cabin at the head of the pallet train.

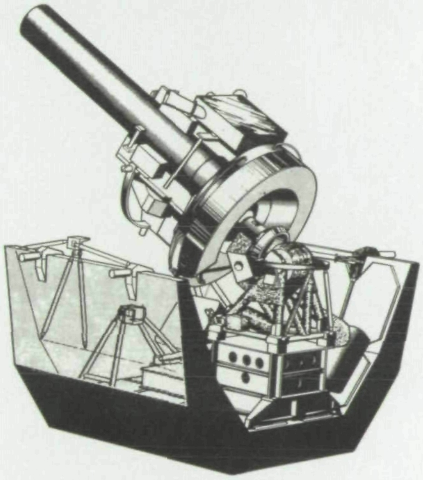
Inside the Shuttle cabin, there are two primary work areas for the seven-member Spacelab 2 crew. The main workstation for the four payload crew members is the aft flight deck. This work area is located directly behind the cockpit, where the three orbiter crew members operate the Shuttle. In addition, biological experiments are performed in the middeck downstairs.

Crew members control the pallet-mounted instruments via computer keyboards located in the aft flight deck. From there, they also control the Instrument Pointing System and operate the Shuttle manipulator arm through an orbiter computer. Two small windows in the aft flight deck overlook the instruments in the payload bay, and two larger windows in the ceiling give the crew a view into space.

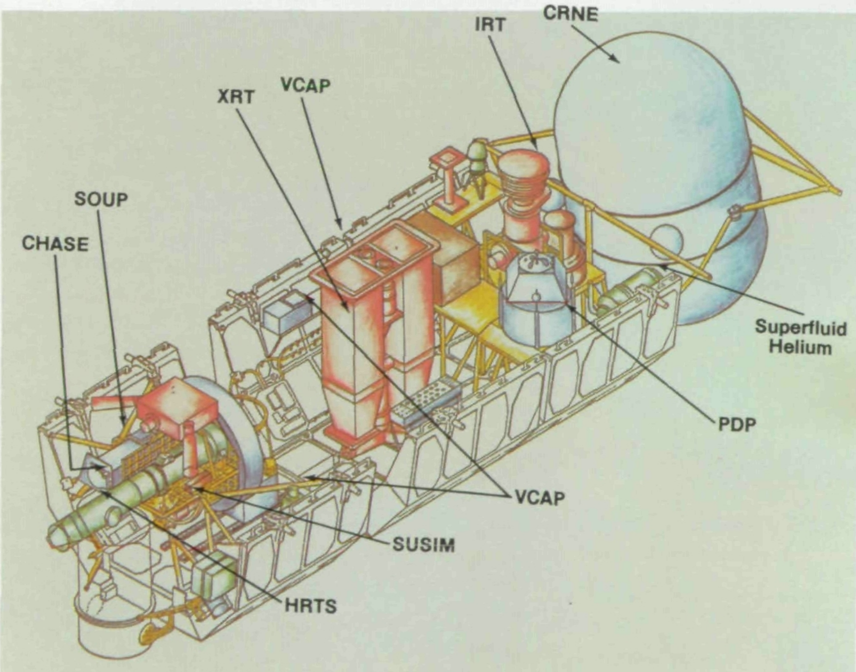
The Spacelab 2 mission is designed to capitalize on several Shuttle-Spacelab capabilities: to carry very large instruments, to launch and retrieve satellites, and to point several instruments independently with accuracy and stability. Mission success depends on active crew involvement in experiment operations, with the benefit of close communication between scientists working in space and scientists on the ground. These unique advantages of Spacelab for supporting instruments and scientists make it possible to do sophisticated research in space. ■



The Instrument Pointing System's capabilities are tested in the laboratory before the Spacelab 2 solar instruments are attached. Developed by the European Space Agency, the pointing system has a relative accuracy of 2 arc seconds (1/1800 of a degree), stable enough to remain pointed at an object the size of a quarter from a distance of three-fourths of a mile.



Instrument Pointing System



SPACELAB 2 CREW

The seven-member Spacelab 2 crew includes a commander, a pilot, and three mission specialists—all assigned to the mission from NASA's astronaut corps—and two payload specialists who are professional scientists. The commander, pilot, and one of the mission specialists are responsible for the smooth operation of the Shuttle. These three are considered the orbiter flight crew.

The two payload specialists and two mission specialists work together as the Spacelab 2 science crew. To ensure maximum scientific return, they work around-the-clock in 12-hour shifts, with one payload specialist and one mission specialist on each shift. The payload specialists are responsible for performing Spacelab 2 investigations. The mission specialists are career astronauts with scientific expertise, whose role is to operate Spacelab systems as well as science instruments.

Payload Specialists

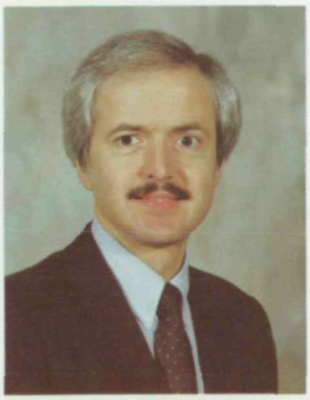
The payload specialists, NASA's newest breed of space professionals, conduct the majority of scientific investigations during this flight. When the mission is over, these scientists return to their positions in laboratories elsewhere to resume their own research. Four scientists were selected by their peers and trained to be Spacelab 2 payload specialists.

All four are co-investigators on one or more of the solar physics experiments. As co-investigators, they have intimate knowledge of the experiment instruments and procedures. All have conducted solar research with balloons, sounding rockets, and satellites, and they are familiar with the design and operation of space instruments and support hardware.

The Spacelab 2 mission is a unique opportunity to continue their research with the added advantage of being in space. Above Earth's obscuring atmosphere, they can observe the sun and stars with greater clarity and make measurements or conduct experiments directly in the very thin electrified gases (plasma) of space. The Spacelab Instrument Pointing System allows them to point several instruments at specific areas on the sun. Working aboard Spacelab, they can see results immediately and make decisions that may affect the outcome of investigations. They do not have to wait until the spacecraft has returned to Earth to see if the instruments worked properly and if the investigations were successful.

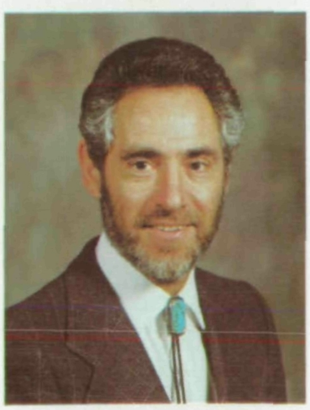
In addition to performing their own experiments, the Spacelab 2 payload specialists also conduct research for other colleagues. The principal investigators who developed each Spacelab 2 experiment formed an Investigator Working Group to

Dr. Loren Acton
Flight Payload Specialist



Dr. John-David Bartoe
Flight Payload Specialist

Dr. Dianne Prinz
Alternate Payload Specialist



Dr. George Simon
Alternate Payload Specialist

guide the mission. This group selected and helped train the four payload specialists to conduct their experiments and further selected two of the four to be flight payload specialists during the mission. The other two play an important role supporting the crew from the Payload Operations Control Center at the Johnson Space Center in Houston, Texas. After years of training, the alternate payload specialists are familiar enough with crew procedures to give essential assistance and to communicate crew needs to the mission management team.

Flight Payload Specialists

DR. LOREN ACTON is a co-investigator for the Spacelab 2 solar magnetic and velocity field investigation. He has a Ph.D. in astro-geophysics from the University of Colorado. Dr. Acton's active career in solar research includes 21 years within the space astronomy research program at the Space Sciences Laboratory of Lockheed Palo Alto Research Laboratory in California. Dr. Acton has been a principal investigator on ten solar rocket experiments and a co-principal investigator for an instrument that is currently studying the sun from the Solar Maximum Mission satellite.

DR. JOHN-DAVID BARTOE is a co-investigator for two of the Spacelab 2 solar investigations. He participated in the design of the instruments, and he served as project scientist for the development of one of them, the solar ultraviolet telescope. With a Ph.D. in physics from Georgetown University, Dr. Bartoe currently is a supervisory astrophysicist at the U.S. Naval Research Laboratory in Washington, D.C., where he has performed solar research for almost 20 years. He has carried out several solar ultraviolet studies with sounding rockets, satellites, and instruments flown on Apollo and Skylab missions.

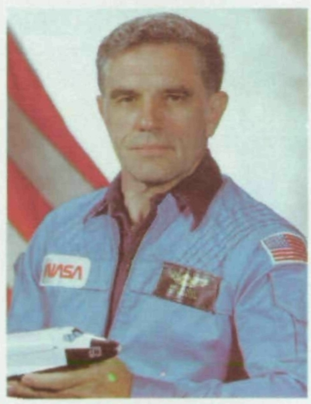
Alternate Payload Specialists

DR. DIANNE PRINZ brings her knowledge of solar-terrestrial observations, optical design, and Shuttle operations to this mission. She is a co-investigator for the Spacelab 2 experiment that monitors solar radiation in the ultraviolet to visible wavelength range. She earned a Ph.D. in physics from the Johns Hopkins University. Since 1971, Dr. Prinz has been a research physicist in the U.S. Naval Research Laboratory's Space Science Division, where she heads the Atmospheric Spectroscopy Section. She participates in all phases of the Naval Research Laboratory's ultraviolet experiments flown on rockets, satellites, and the Space Shuttle.

DR. GEORGE SIMON is the senior scientist in the Solar Research Branch of the Air Force Geophysics Laboratory at the National Solar Observatory in Sunspot, New Mexico, where he participates in observational and theoretical research. He has specialized in studies of the sun's velocity, magnetic, and intensity fields since 1960, and he is a co-investigator for the Spacelab 2 experiment analyzing these solar features. Dr. Simon has a Ph.D. in physics from the California Institute of Technology and has collaborated on a number of NASA experiments, including the Orbiting Solar Observatories and the Solar Maximum Mission. He developed the idea for an imaging network that allows scientists on the ground to relay current information about interesting solar events to the Spacelab 2 investigators and crew.

Mission Specialists

Dr. Anthony England
Mission Specialist



Dr. Karl Henize
Mission Specialist

Mission specialists share several responsibilities on a Spacelab flight. They are career astronauts who are responsible for operating the Spacelab and orbiter systems that support the payload, particularly the Instrument Pointing System and the Remote Manipulator System. Their expertise as scientists also prepares them to work with the payload specialists and principal investigators in conducting experiments. Two of the Spacelab 2 mission specialists are trained in all of the scientific investigations.

DR. ANTHONY ENGLAND is a geophysicist with a Ph.D. in earth and planetary sciences from the Massachusetts Institute of Technology. He was selected as a scientist-

astronaut by NASA in 1967 and subsequently served as a support crew member on two Apollo flights. For several years in the mid-1970's, Dr. England worked as a research geophysicist with the U.S. Geological Survey and then returned to NASA as a mission specialist. Since 1979, he has participated in the development of Shuttle and Spacelab missions.

DR. KARL HENIZE is an astronomer who was selected as a scientist-astronaut in 1967. He has a Ph.D. in astronomy from the University of Michigan and has been associated with various observatories in the United States and abroad. Dr. Henize was a support crew member on Apollo and Skylab missions and was the principal investigator for an ultraviolet telescope flown on Skylab. He is now a member of a team developing a Shuttle telescope for ultraviolet and optical astronomy.

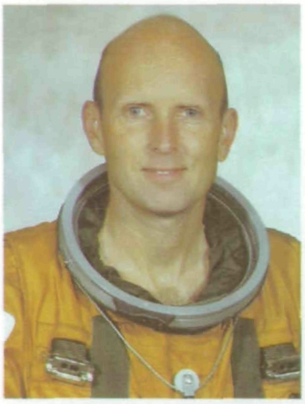
Flight Crew

Spacelab 2 is a very busy mission for the flight crew, which includes the commander, pilot, and one mission specialist. In addition to normal Shuttle operations, they must make many maneuvers to meet the solar and celestial viewing requirements of various science investigations. Plasma physics experiments require orbiter maneuvers to deploy, fly around, and retrieve a small satellite. The flight crew also is responsible for engine burns above designated ground sites for plasma depletion studies. The pilot and mission specialist alternate 12-hour shifts, and the commander is on duty during all critical operations, especially launch and landing.

C. GORDON FULLERTON (Colonel, USAF), the Spacelab 2 commander, is responsible for overseeing the entire mission. He was the pilot for the third Shuttle mission and has more than 15 years of experience as an astronaut. Col. Fullerton has an M.S. in mechanical engineering from the California Institute of Technology.

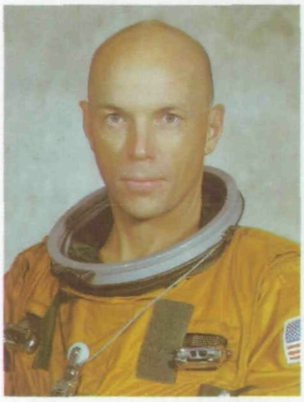
ROY D. BRIDGES, JR., (Colonel, USAF) the Spacelab 2 pilot, assists the commander with Shuttle operations. He was selected as an astronaut candidate by NASA in 1980. He has an M.S. in astronautics from Purdue University.

DR. STORY MUSGRAVE has almost 20 years of experience as a NASA scientist-astronaut. He earned an M.D. from Columbia University, and he has participated in the design of NASA's spacesuits and life support equipment. Dr. Musgrave was a mission specialist on the sixth Shuttle flight. On the Spacelab 2 mission, he works with the commander and pilot to handle the busy schedule of Shuttle operations. ■



C. Gordon Fullerton
Commander

Roy D. Bridges Jr.
Pilot



Dr. Story Musgrave
Mission Specialist

Ham Radio/TV Operators to Communicate with Spacelab 2

Amateur radio and television operators have joined with NASA to create a network that allows enthusiasts worldwide to participate in the mission. A small ham radio operated by mission specialist Owen Garriott during Spacelab 1 created so much excitement that NASA decided to work with radio operators to create a more elaborate system for Spacelab 2. The system allows amateur clubs to talk to crew members, talk to each other from remote locations, watch television transmitted from the flight deck, and help crew members perform radio signal experiments. The American Radio Relay League (ARRL) is working with the NASA/Johnson Space Center Amateur Radio Club to assemble equipment and organize clubs internationally to participate in the mission.

Mission specialist Tony England and payload specialist John-David Bartoe, both amateur radio buffs, will operate the system during their free time. However, it can also be used in unattended modes while England and Bartoe are busy with Spacelab 2 science. The ham radio and television operate on the 2- or 10-meter bands and are located in the orbiter middeck. A small antenna is mounted in the payload bay.

The system works in four modes, but only one mode can be used at a time. The first mode allows communications on the 2-meter band between radio operators on the ground and Spacelab crew members. To give more people a chance to participate, sessions have been scheduled with amateur radio clubs, especially school clubs.

The second mode uses the Shuttle-Spacelab as a giant antenna for relaying communications between ham radio users at remote locations. The Spacelab antenna becomes what ham users call a "repeater," an antenna in line-of-sight that can be used to transmit signals elsewhere. When the system is in this mode, users within approximately 1,600 kilometers (1,000 miles) can send voice signals up on the 2-meter band, and the signals will travel back down on the 10-meter band to any other location within 1,600 kilometers of the orbiter.

The third mode is for amateur television operators. A camera in the cockpit will send pictures of the crew through a slow-scan television mode that operates in the 10-meter band. Images will be available to any amateur television station within 1,600 kilometers of the orbiter. In this mode, the system is also capable of receiving an image from a television station on the ground, storing the image, and then sending it to a television station in another part of the world. In this way, operators can use Spacelab to send greetings abroad.

A fourth mode, called the experimental mode, lets amateurs help investigators do some simple experiments that explore radio wave propagation in the upper atmosphere. The Shuttle travels through the atmospheric region (the ionosphere) that affects radio wave transmissions. The crew will transmit radio signals of varying strength and frequency; by monitoring who receives them, scientists will be able to track the path of the radio signals in the ionosphere.

MISSION DEVELOPMENT & MANAGEMENT

Supporting every space venture are many planners who coordinate training, assemble scientific equipment, and decide when and how each investigation will operate. Years before launch, managers and engineers are busy planning and organizing activities to flow smoothly during a Spacelab mission. By launch day, everyone involved in the Spacelab 2 mission is working together as a team with one common goal: a successful mission with maximum scientific return for each investigation.

Many members of the Spacelab 2 team are stationed at the Marshall Space Flight Center in Huntsville, Alabama, the NASA center responsible for planning and directing this mission. The mission manager, Roy C. Lester of the Marshall Center, works with other members of the Spacelab Payload Project Office to keep all mission personnel working in concert. He leads a team effort to ensure that the science payload satisfies the needs of the user scientists, utilizes Shuttle-Spacelab resources efficiently, and operates well during flight. This group works closely with other NASA organizations involved in preparing the Shuttle and Spacelab for launch and conducting flight operations.

The planning team coordinates all the activities that must be completed before the Shuttle-Spacelab is launched. During the mission, they continue to aid the crew and the scientists in collecting data, resolving problems, and rescheduling payload operations as necessary.

Choosing Experiments

To place an investigation on Spacelab, scientists engage in a tough competition judged by

Spacelab 2 investigators meet to discuss detailed plans for the mission.

The Marshall mission management team works around-the-clock to ensure mission success.

their peers. All the competitors must meet two requirements for acceptance: their experiments must promise meaningful scientific results and be suitable for flight on the Shuttle.

When NASA announces flight opportunities, many research ideas are submitted by the worldwide scientific community. NASA then selects investigations that are compatible with one another and with Spacelab's capabilities. Of the 13 Spacelab 2 investigations, 11 were developed by scientists in the United States and 2 by scientists in the United Kingdom.

Many of the investigators chosen to fly experiments aboard Spacelab 2 already have sent related experiments into space. They have studied the sun and stars, probed the upper atmosphere, and observed biological systems with instruments on balloons, small rockets, and satellites. Doing experiments in a space laboratory is a logical step in the progression of their research.

Spacelab 2 payload specialists John-David Bartoe and Loren Acton practice experiment operations in a mockup of the aft flight deck.

Planning for Science

Spacelab missions are designed to give participating scientists a voice in guiding the mission. The principal investigators, who are the chief scientists for each experiment selected for flight, form an Investigator Working Group and convene periodically to plan the Spacelab 2 mission. The mission scientist, Dr. Eugene W. Urban of Marshall Space Flight Center, chairs the group and coordinates activities with the mission management team.

This group helps to decide how all the experiments share valuable Spacelab resources, such as electrical power and crew time. They carefully identify their scientific priorities in case the mission is shortened or lengthened. In addition, these scientists and their co-investigators participate actively in crew training.

Training the Mission Team

Although the payload specialists and mission specialists for Spacelab 2 are professional scientists or astronauts, they must train for the mission to ensure the success of each investigation. The major part of crew training is conducted by the principal investigators in their own laboratories. There, they instruct the crew members in the theory, hardware, and operation of their experiments.

Training for overall experiment operations takes place at Marshall Space Flight Center. Inflight operations involving the Spacelab computer system are realistically simulated in the Spacelab 2 mockup in the Payload Crew Training Complex there.

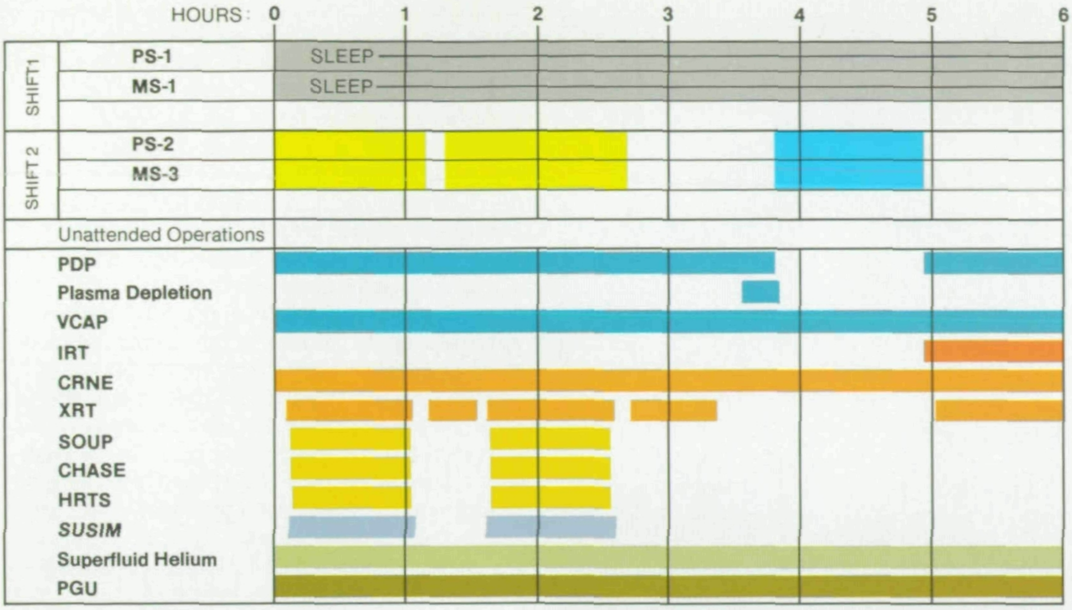
Part of the crew's training involves the basic skills necessary for living and working safely on board the Shuttle and Spacelab. Medical, emergency, and survival skills as well as the normal routines of living in a spacecraft are practiced in training programs at Johnson and Kennedy Space Centers.

In addition to the crew, the principal investigators and the entire mission management team undergo training for their activities in the control center during the mission. Everyone involved in the mission participates in simulations to practice planned operations, communications, and problem solving. It is the mission manager's responsibility to coordinate all training exercises and to ensure that the entire mission team is well-prepared.

Planning the Mission

Time in space is precious. If scientific success is to be achieved, events cannot occur at random. An around-the-clock schedule of events, a timeline, must be prepared in advance and followed as closely as possible.

Mission planning is a complex task that involves the merger of all crew activities, experiment requirements, Spacelab resources, and Shuttle maneuvers into an efficient operating plan. Each experiment is assigned time slots during which it receives the necessary power, crew attention, and computer support



Sample Spacelab 2 timeline, showing crew activities and experiment operations for a six-hour period of the seven-day mission

for its operation. Mission planning produces a very precisely coordinated sequence of operations for maximum efficiency.

Later, during the flight, the timeline is revised periodically in response to unexpected difficulties or opportunities. Replanning occurs throughout the mission, but the guiding philosophy is to adhere as closely as possible to the master schedule.

Developing Experiment Hardware

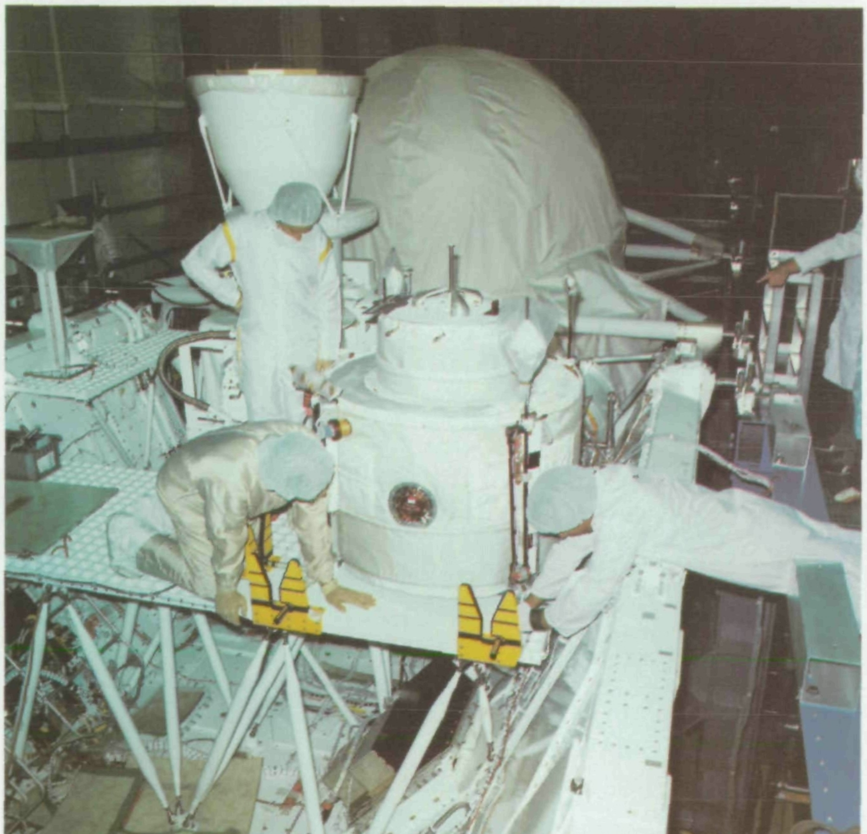
Experiment hardware is developed by investigators in collaboration with NASA and private industry. The Marshall management team has refined the experiment development process, taking advantage of Shuttle capabilities and investigators' experience to achieve the desired science at a relatively low cost. As a result, sophisticated new instruments have been economically developed for Spacelab missions.

Instruments are designed not only to fulfill their research purpose but also to fit with other experiments into the size, weight, and power supply capabilities of Spacelab. For the sake of economy, existing equipment is used as much as possible, and some of the hardware is designed for reuse on future missions. The experiment teams and the mission manager stay in close communication to ensure that instruments and related support hardware are well coordinated and are compatible with the Shuttle and Spacelab.

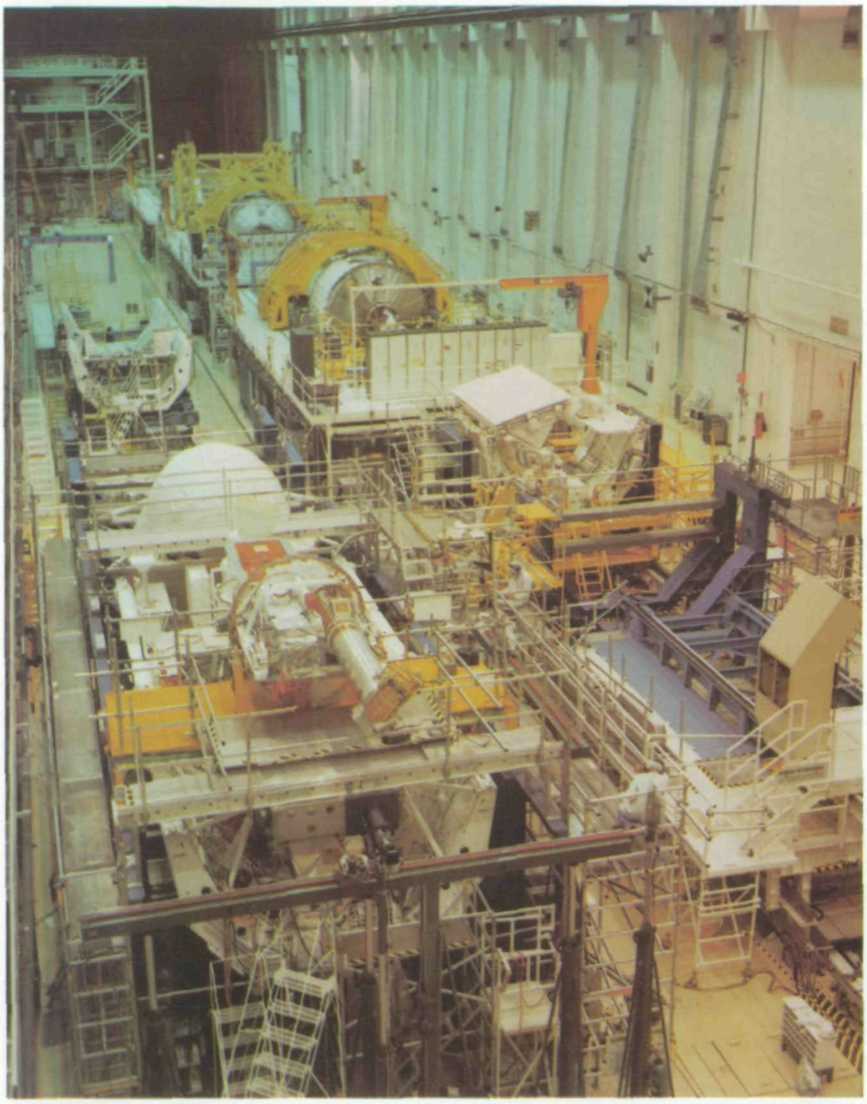
Putting the Payload Together

For a successful mission, all Spacelab systems and all experiments must be assembled so they work properly. This process, called payload integration, occurs in several phases during the life of the mission.

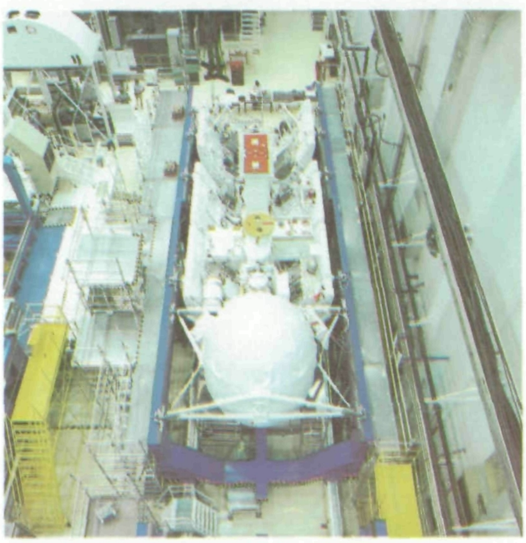
Initially, the requirements (such as volume, electrical power, computer time, crew time) of each experiment are evaluated and a layout is designed. This blueprint ensures that



Technicians mount experiment hardware at precise locations on the Spacelab 2 pallets.



Eauibment for several Spacelab missions, including Spacelab 2 (left front), is assembled in the Operations and Checkout Building at Kennedy Space Center.



Spacelab 2 Integration

all users can share Spacelab's accommodations compatibly. Cables connecting instruments to Spacelab's power supply, computer, and data system are also laid out on paper.

Instruments are then completed and individually tested at the investigators' laboratories. Mounting brackets and cables are fabricated by NASA, and analyses are performed to ensure that the entire payload is mechanically sound and safely operable.

Later, instruments are shipped to the launch site for assembly of the total payload and installation into Spacelab according to the developed blueprint. Components are attached to the experiment pallets and the special support structure, and all circuits and connections are tested. The mission management team schedules and coordinates all payload integration activities performed by NASA and contractor personnel.

About a month before launch, Spacelab is placed inside the Shuttle orbiter and all connections are checked. Then the loaded orbiter is moved to the Vehicle Assembly Building to be attached to the external tank and solid rocket boosters. Finally, the fully assembled Shuttle-Spacelab is moved to the launch pad.

Making it Happen

During a Spacelab flight, the hub of activity is the Payload Operations Control Center in Houston. The Marshall Center's mission management staff monitors and manages Spacelab 2 payload operations from this site. Like the Mission Control Center, this area contains banks of television monitors, computers, and communications consoles. The Payload Operations Control Center becomes home to the management and science teams who work around the clock to guide and support the mission. All the months of preparation come to a focus here as personnel on the ground work in concert with the crew in space to make the mission happen as planned.

For the mission, all Spacelab 2 principal investigators and their teams of scientists and engineers set up work areas in the Payload Operations Control Center. They bring whatever they need to participate in the flight operation of their experiments. Through computers, they can send commands to their instruments and receive and analyze experiment data. Instantaneous video and audio communications make it possible for scientists on the ground to follow the progress of their research almost as if they were in space with the crew.

This "real-time" interaction between investigators and crew is probably the most exciting of Spacelab's many capabilities. As principal investigators talk to the payload specialists during the mission, they consult on experiment operations, make decisions, and share in the thrill of gaining new knowledge.

During this mission, scientists around the world are participating in solar and plasma physics investigations. Solar scientists receive data directly from space and from ground-

based observatories through a solar imaging network. After a quick analysis, they can relay to the crew pertinent information for planning the next day's observations. Prescribed ground observatories around the globe are key participants in detecting and studying effects of Shuttle thruster firings. At specific times during the mission, scientists at these sites observe the ionosphere while the Shuttle acts as their experimental probe.

While the investigators monitor their own experiments, the mission scientist and other key members of the mission management team are also busy in the control center overseeing the full range of Spacelab operations. They are supported by a payload flight operations cadre at the Johnson Center and by Spacelab experts who are monitoring the mission from the Huntsville Operations Support Center at the Marshall Center. Assisted by these groups, the mission management team assesses and responds to up-to-the-minute information, replans as necessary, advises the crew of changes in the schedule, and works to resolve problems and keep the mission progressing well.

Collecting Data

Information pertinent to the in-flight operation of Spacelab 2 investigations is received through the data management system in the Payload Operations Control Center. The data flow during a Spacelab mission is tremendous.

To handle the steady flood of scientific and engineering data, a special Spacelab Data Processing Facility was established at Goddard Space Flight Center in Greenbelt, Maryland. This facility records, separates, and organizes the mass of incoming data by experiment and sends data out to investigators after the mission. In addition to the data received in Houston during the mission, scientists may obtain from Goddard computer tapes, voice recordings, and video tapes that contain more detailed information about their experiments.

Film, tapes, plants, experiment samples, and other such data and specimens are removed promptly after the Shuttle lands for postflight evaluation. Later, experiment equipment is returned to the principal investigators. The Spacelab 2 mission undoubtedly will produce immediate discoveries, but full analysis of all returned data may take several years. Within this mass of data, the potential exists for practical benefits on Earth as well as quantum leaps in our knowledge.

Recycling Equipment

A unique advantage of Spacelab is that the laboratory and many of the individual instruments are designed to be reused on other missions. The Spacelab 2 mission capitalizes on this capability by reusing four scientific instruments that were among the first used for scientific research on the Shuttle. Sponsored by the diverse fields of biology, space plasma physics, and solar physics, these instruments flew on the third Shuttle mission, which was a "pathfinder" mission to determine what science could be performed successfully on the Shuttle. The instruments not only operated well in the Shuttle environment but also produced such interesting results that the scientific community was prompted to reuse them for follow-up investigations.

After this mission, the Spacelab hardware will be dismantled, inspected and, if necessary, repaired or modified. Some components may be required immediately for other Spacelab missions; others will be placed in inventory for future use. Some of the Spacelab 2 instruments are already scheduled to fly on future Spacelab missions. ■

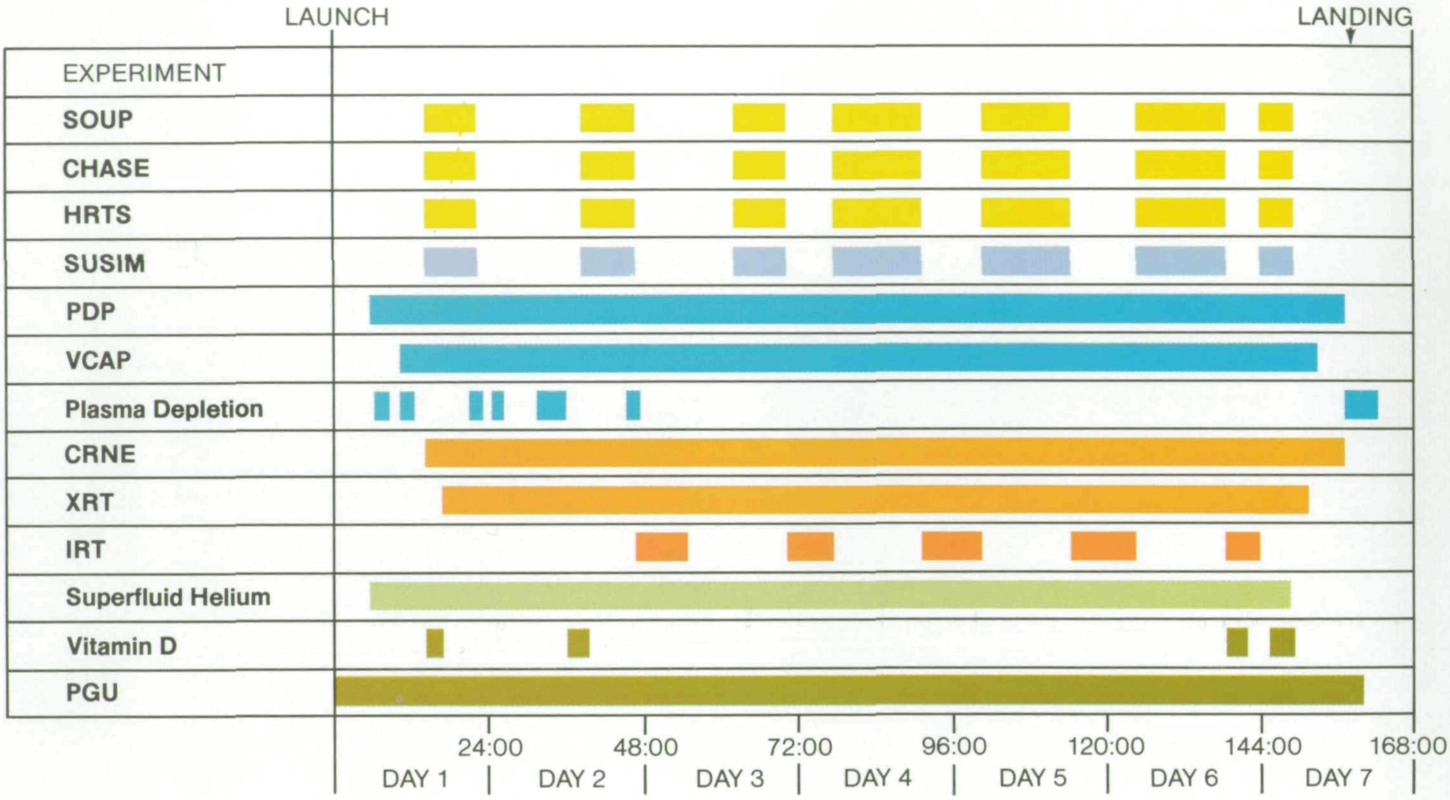
Scientists talk to the crew and command their instruments from workstations on the ground at Johnson Space Center.

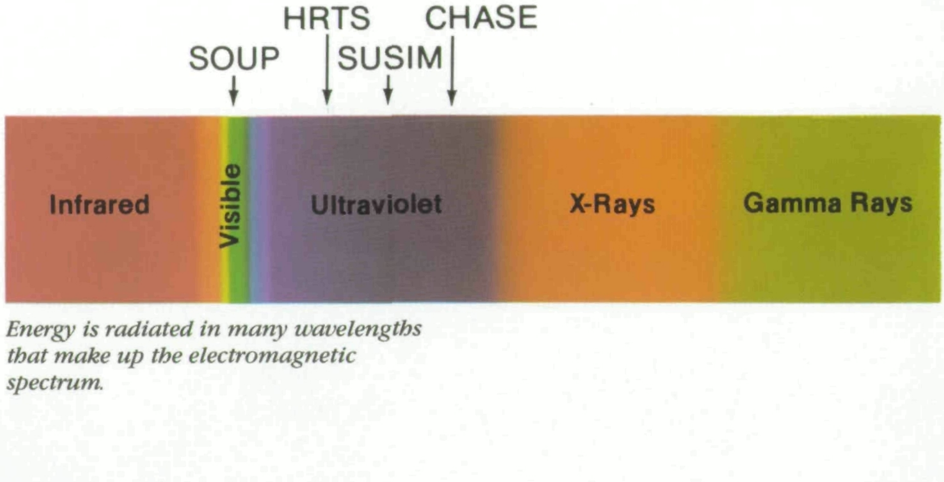
SCIENTIFIC INVESTIGATIONS

Spacelab 2 is a laboratory and observatory for 13 investigations in 7 scientific disciplines: solar physics, atmospheric physics, plasma physics, high energy astrophysics, infrared astronomy, technology research, and life sciences. On this mission, several major new scientific instruments are introduced, while four others are making their second flights aboard the Shuttle. Several of the instruments are involved in joint investigations, observing the same phenomena with different measuring techniques. Over the next decade, many of the Spacelab 2 instruments will be used routinely in remarkable laboratory.

The following summaries include the purpose, importance, and method for each Spacelab 2 investigation. The official investigation name, the principal investigator's name and affiliation, and the co-investigators' names and affiliations are given for each investigation.

Mission overview, showing scheduled experiment operations





Energy is radiated in many wavelengths that make up the electromagnetic spectrum.

Solar Physics

The sun is a complex and variable star. It is the only star close enough for astronomers to observe in fine detail. The general goal of solar physics research is to understand the structure and dynamics of the sun, its different layers, magnetic fields, energy processes, and activity cycles.

Only one solar layer, the photosphere, is normally visible to us on Earth as the sun's surface. During a solar eclipse when the moon blocks the bright light of the photosphere, we can see the corona, the sun's outermost layer. The corona and the other solar layers are difficult to study because they radiate most of their energy in ultraviolet wavelengths rather than visible light, and the bright light of the photosphere masks the little visible light that they do emit. Special instruments are required for detecting and studying the invisible ultraviolet solar radiation.

Radio, microwave, infrared, ultraviolet, X-ray, and gamma ray radiation are the other types of energy emitted by astrophysical objects. These emissions, along with visible light, form the electromagnetic spectrum, a scale of radiation based on energy wavelength. The customary unit of wavelength measurement is the Angstrom (Å), one ten-billionth of a meter. The human eye is sensitive to visible energy in the 4000 Å to 7000 Å range, but we cannot see the shorter wavelengths of ultraviolet, X-ray, and gamma ray radiation or the longer wavelengths of radio, microwave and infrared radiation.

The electromagnetic spectrum gives us clues to the chemistry and composition of distant objects because different elements absorb or emit radiation at certain characteristic wavelengths, or spectral lines. Some lines appear in the visible range and others appear elsewhere in the spectrum; these lines are signatures that uniquely identify the chemical elements and the energetic processes affecting them. The separation of radiation into its constituent spectral lines, as a prism separates light into colors, is called spectroscopy. This is an important research technique in solar physics and astronomy.

Solar researchers interpret spectral data to understand the composition and behavior of solar gases. By studying the solar spectrum, they can explore the high temperatures, dynamic events, and physical structures that are associated with the sun's magnetic fields. When magnetic fields become kinked below the sun's surface, they erupt through the photosphere and form dark blemishes known as sunspots. When the intense fields in sunspots become unstable, they produce solar flares, tremendous explosions that send matter hurling through space. Solar flares may result from the huge energies released by the annihilation of magnetic fields arching above the solar surface between sunspots. These fields can stretch between points of solar activity as distant as the Earth is from the moon. They appear, shift, change shapes, and gradually disappear to be replaced by new magnetic fields generated by large-scale motions of the hot ionized gases hidden beneath the visible photosphere.

Because Earth's atmosphere absorbs most electromagnetic radiation, scientists cannot adequately study the sun from the ground. Spacelab takes instruments above the distorting and filtering effects of the atmosphere to collect spectral information that is not available to terrestrial observatories and also to make more accurate measurements of the radiation that can be studied from the ground.

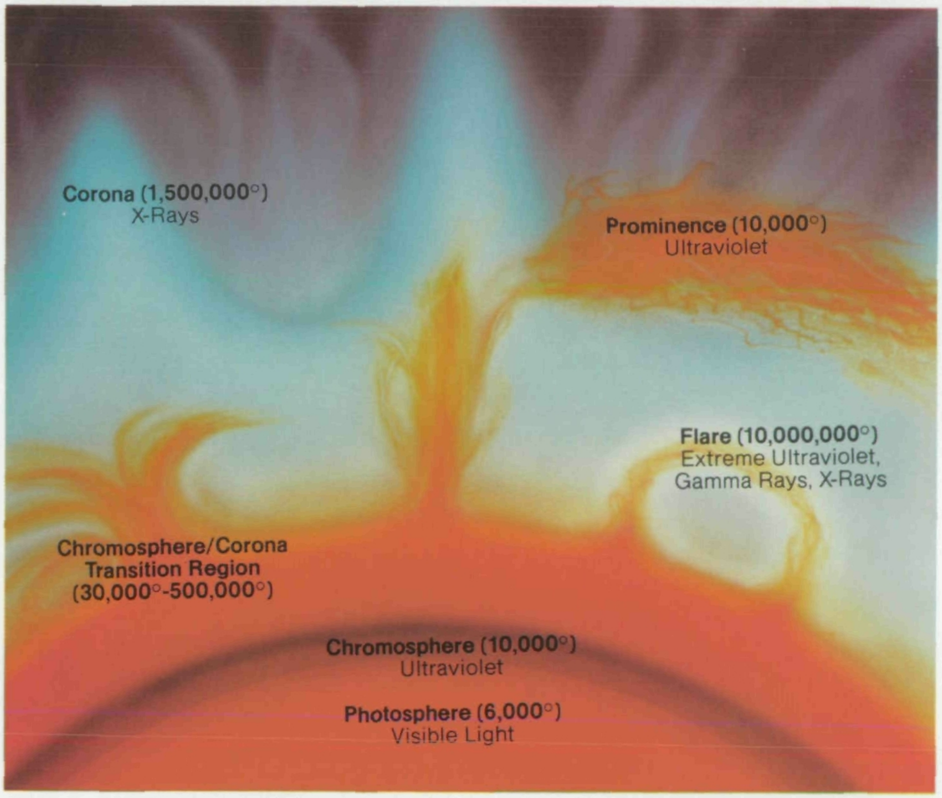
Spacelab 2 carries three solar physics instruments capable of viewing visible and ultraviolet solar features. The instruments are mounted on the Instrument Pointing System, which can aim the detectors at solar sites accurately enough to resolve details. Stable pointing is important, for some of the detectors must form sharp images of precisely specified areas of the sun. The pointing system can also point the instruments at the same solar feature, which allows them jointly to collect a wealth of information at once.

One of the Spacelab 2 solar physics instruments studies magnetic field structures that are woven throughout the layers of the sun and play key roles in solar processes. Because it is a visible light detector, it allows scientists to look at low altitudes near the surface of the sun. Another instrument observes ultraviolet radiation from higher, hotter regions and watches the development of structures and changing activity in the sun's outer layers. A third instrument measures helium in the outermost region, the solar corona. Because helium constitutes 10 percent of all the atoms in the universe, a better understanding of its abundance on the sun could give insight into the evolution of stars and the origin of the universe.

This instrument complement was selected specifically to investigate the solar atmosphere as a system. The resultant data and images can be used to make three-dimensional maps of the sun. By making coordinated measurements of the sun's different atmospheric layers, scientists can learn more about how this star really works, how energy is transferred from low altitudes to great distances, and how gases are heated from a few thousand degrees to more than a million degrees as they move outward.

The Spacelab 2 payload specialists are very actively involved in the operation of these instruments, using them in concert to gain as much information as possible about solar features. All the Spacelab 2 solar investigations share data and make joint observations for increased scientific return. In addition, an atmospheric physics investigation that measures fluctuations in solar ultraviolet energy complements the solar instruments. Working together, these instruments make a composite portrait of the sun and provide more accurate knowledge of its intricate patterns and processes.

Layers of the sun are characterized by different temperatures and emissions.

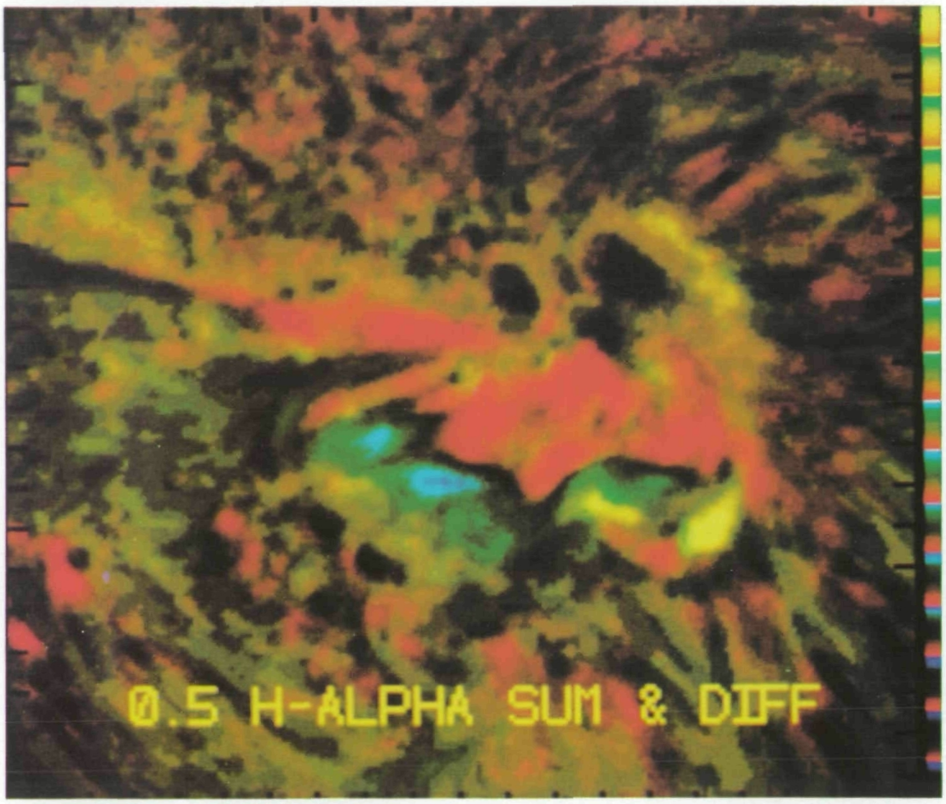


Solar Magnetic And Velocity Field Measurement System

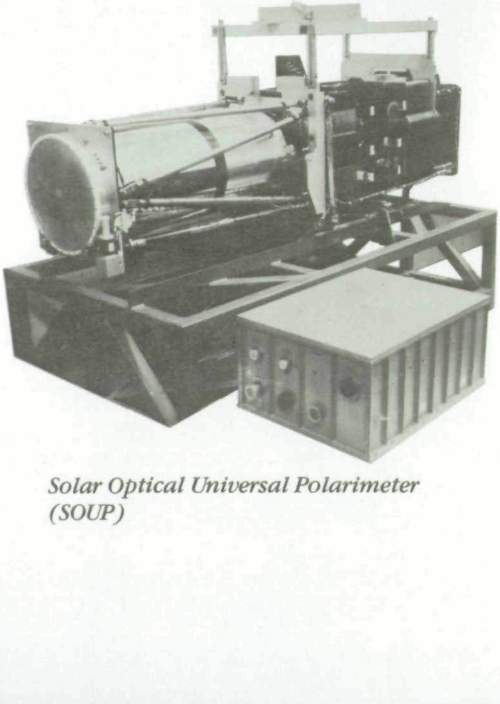
Solar Optical Universal Polarimeter (SOUP)

Dr. Alan M. Title
Lockheed Solar Observatory
Palo Alto, California

Purpose: The objective of this investigation is to observe the strength, structure, and evolution of magnetic fields in the solar atmosphere and to determine the relationship between these magnetic elements and other solar features.



A hydrogen-alpha image, made by the SOUP engineering model during ground tests, was color-coded by computer to show flow patterns in the chromosphere. Red-orange areas show material flowing down into the solar surface, and blue-green areas show upward flows.



Solar Optical Universal Polarimeter (SOUP)

Importance: The major thrust of space-based solar experimentation has been to study wavelengths not visible from the ground, but scientists would also like a sharper image of the visible sun. Turbulence in Earth's atmosphere blurs our view of the sun so much that optical images made from ground observatories do not show fine details or subtle changes from one image to the next. Aboard Spacelab 2, the Solar Optical Universal Polarimeter (SOUP) is able to focus on solar details and produce high-quality filtered images, photographs, and movies.

Solar physicists are particularly interested in the role of magnetic fields that are laced throughout the sun's layers. These magnetic fields, some of them thousands of times stronger than Earth's, play a crucial role in determining the structure and dynamics of the solar atmosphere from the deepest levels of the photosphere upward through the chromosphere and corona and out into the interplanetary medium.

Changes in the position and strength of magnetic fields indicate that energy is being stored or released. Short-term changes in magnetic fields have been impossible to detect from ground observatories. This has made it difficult to determine the relationship of magnetic fields to other solar structures, such as granules.

Granules pockmark the photosphere in an irregular pattern of cells, each about one-tenth the size of the United States. Granules are hot, rising convection bubbles that carry to the surface the tremendous heat produced in the burning nuclear furnace at the core of the sun. While granules are formed perhaps 1,000 kilometers below the photosphere, supergranules, which are 400 times larger than granules, originate even deeper inside the sun, probably 15,000 kilometers or more.

SOUP can study the relationship between magnetic fields, granules, and supergranules. Its detectors can trace individual magnetic elements over periods long enough to cover the 5- to 20-minute granulation lifetimes and the 20- to 40-hour supergranulation lifetimes. At the same time, it can produce high-resolution images that reveal the strength, geometry, and evolution of magnetic fields. These data will be used in making magnetic field maps of the regions studied by all three solar instruments during the Spacelab 2 mission.

Method: The Solar Optical Universal Polarimeter is an elaborate instrument set. The assembly mounted on the Instrument Pointing System houses a 30-centimeter (12-inch) Cassegrain telescope, a video camera with a tunable filter system, a white-light video camera, a video processor, and two film cameras. The telescope is mounted on movable legs that allow SOUP to observe any point on the sun while the Instrument Pointing System is aimed elsewhere on the solar disc. A fine guidance system keeps the image extremely stable for the cameras. A separate electronics box, to aid in telemetering data to the ground, is

mounted on the first pallet.

The SOUP telescope is sensitive to visible wavelengths (4800 Å to 7000 Å). Light entering the telescope passes through polarization filters that admit only those wavelengths oriented in a selected plane. Because the polarization state of light from atomic processes is affected by the magnetic fields within which it is generated, scientists can detect invisible magnetic fields by analyzing images made in polarized light.

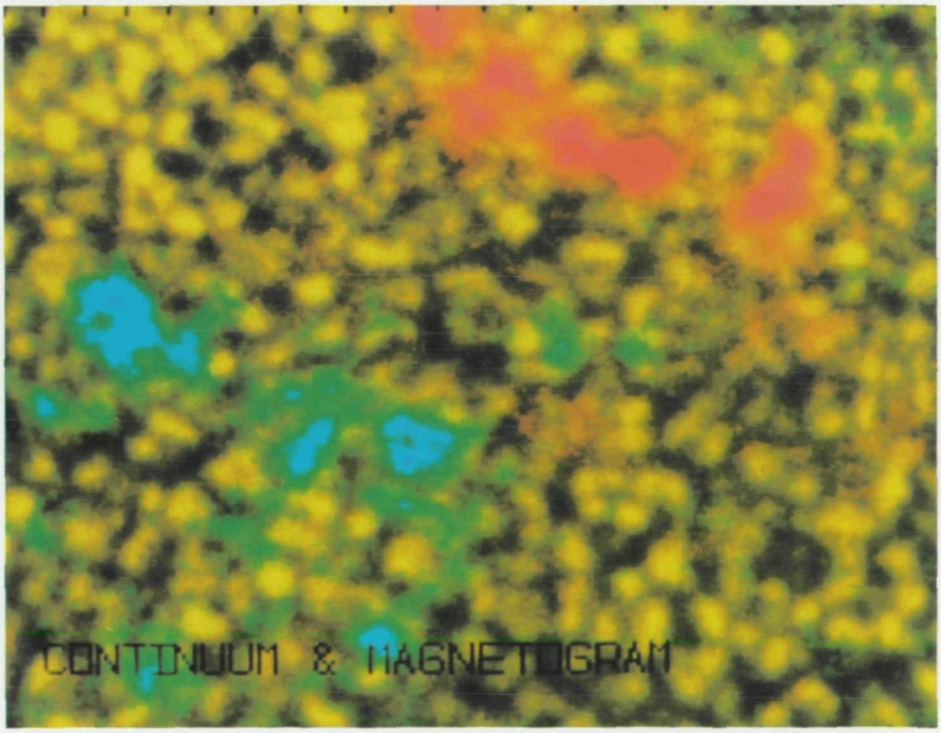
During solar observation periods, the crew operates the SOUP instrument to build up three-dimensional images of solar features. The filter system enables them to tune the instrument to many different states of polarization and many different wavelengths. Working with a computer and video monitor, they can add, subtract, multiply, and divide images to create composite images of interesting solar features. By manipulating the instrument in this manner, they can look at different altitudes in the solar atmosphere and extract information about the physical processes occurring there.

The composite image from the video camera, tunable filter, and video processor shows in shades of light and dark where a magnetic field is strong or weak and how it is oriented, north or south. Similarly, other images can reveal whether the velocity field is strong or weak and whether gas is moving toward or away from the observer. While the tunable filter camera with its narrow bandpass is being used to produce images of the short-term changes in details of solar features, the white light video camera is making direct movies of a larger region of the solar disc and recording solar granule activity for periods of up to an hour. This combination of narrow band and broad band cameras for both composite and real-time images gives the instrument unprecedented versatility for solar observations.

The resultant images from both cameras can be transmitted to investigators on the ground or displayed as a television image at the aft flight deck workstation. Once a desired image is achieved, it can be photographed by a film camera associated with either video camera. As the crew members view images, they can use the information to point the SOUP telescope at interesting areas of solar activity.

During the mission, the payload specialists and scientists in the control center and at observatories around the world watch for new solar active regions that can be observed from Spacelab. If a solar flare should occur, SOUP can measure changes in the magnetic field pattern as stored magnetic energy is converted into the high energy flare radiations. After the mission, the data can be used to make theoretical models of magnetic structures and physical processes in the solar atmosphere.

Co-investigators for this experiment are Spacelab 2 payload specialist Dr. Loren Acton, Thomas P. Pope, Harry E. Ramsey, Dr. Robert C. Smithson, and Dr. Theodore D. Tarbell, all of Lockheed Solar Observatory; Dr. John W. Harvey, Dr. John Leibacher, and Dr. William L. Livingston, all of the National Solar Observatory in Tucson, Arizona; Dr. Robert W. Milkey of AURA, Inc. in Tucson, Arizona; Dr. George W. Simon, Spacelab 2 alternate payload specialist, of the Air Force Geophysics Laboratory in Sunspot, New Mexico; Dr. Simon P. Worden, a United States Air Force scientist stationed in Washington, D.C.; and Dr. Jack B. Zirker of the National Solar Observatory in Sunspot, New Mexico.



Solar granulation appears as bright yellow areas in this filtergram, made with the SOUP engineering model. The magnetic field has been overlaid in color by a computer; red-orange indicates the location of south-directed fields and blue-green indicates that of north-directed fields.

Coronal Helium Abundance Spacelab Experiment (CHASE)

Dr. Alan H. Gabriel
Rutherford Appleton Laboratory
Chilton, United Kingdom

Prof. J. Leonard Culhane
Mullard Space Science Laboratory
University College, London

Purpose: The goal of this experiment is to determine accurately the helium abundance of the sun. The temperature, density, and composition of coronal gas can be derived from measurements of the intensities of ultraviolet emissions.

Importance: The corona is the tenuous outer layer of the sun's atmosphere that is normally visible from Earth only during total solar eclipses or with special instruments. Its lower boundary is well defined by a narrow transition zone having a very steep rise in temperature of more than 1,000,000° C and a correspondingly sharp drop in density. The extremely high coronal temperature causes ionized helium, hydrogen, oxygen, carbon, and other solar elements to radiate energy in specific wavelengths, mainly in the extreme ultraviolet (EUV) range below 1200 Å.

Ratios of the intensities of particular emission lines can yield valuable information about the composition of the solar atmosphere as well as its temperature and density. Measurements of certain helium and hydrogen emissions are particularly important for deriving an accurate ratio of helium to hydrogen in the sun. Because it contributes approximately 10 percent of the solar mass, helium plays an important role in models of the solar interior; it can be used to determine the structure of the energy-generating core and the rate at which that energy is transferred to the surface. In addition, the abundance of helium is thought to have changed little since the beginning of the universe, so its measurement is significant for cosmological models. While the presence of helium in the sun is known, its abundance there has not yet been measured accurately.

Designing an instrument to measure the sun's extreme ultraviolet radiation is a difficult technical challenge. Special techniques must be used to focus the very short EUV wavelengths because they do not reflect from normal mirror surfaces, and even a minute percentage of Earth's atmosphere is sufficient to absorb them. Spacelab provides a stable research facility well above the absorbing atmosphere.

Method: The CHASE instrument is a combination of a grazing incidence (shallow angle) telescope and a Rowland circle spectrometer with wavelength coverage from 150 Å to 1350 Å. The 28-centimeter (11-inch) telescope focuses a solar image onto an entrance slit of the spectrometer, which contains eleven channels for simultaneously detecting preselected emission lines of particular interest and another detector for simultaneous monitoring of several wavelengths in the 150 Å to 220 Å region.

Two detectors measure specific hydrogen and helium lines, each directly associated with hydrogen and helium abundance. The others record emission lines of iron, carbon, oxygen, and sulfur, from which the temperature and density of the solar atmosphere can be derived.

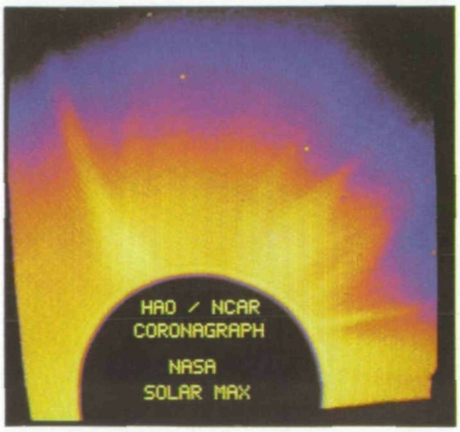
The CHASE assembly is pointed at observation targets by crew control of the Instrument Pointing System. Operation of the instrument by the Spacelab crew has been simplified by the use of a microprocessor, which automatically formats data and controls movements of the spectrometer slit and telescope mirror. The payload specialist initiates an observation sequence by entering a command on the computer console keyboard and then monitoring the progress of the observation on the display screen.

A sequence of observations consists of a one- or two-dimensional scan of various solar features, including sites on the solar disc, the edge of the sun (the limb), and the corona above the limb. From these images, scientists can derive temperature and density variations at various wavelengths to investigate how they change with position, height, or time. A one-dimensional scan taken radially across the limb determines how such parameters vary with height in the corona.

Throughout the mission, the CHASE data are continuously analyzed by scientists in the Payload Operations Control Center who supply the payload specialists with solar data from ground-based and satellite telescopes, help select interesting solar features, and optimize each day's program of observation.

Co-investigators for this experiment are Keith Norman and Dr. John H. Parkinson of University College London, and Dr. James Lang and Bruce E. Patchett of Rutherford Appleton Laboratory.

Coronal Helium Abundance Spacelab Experiment (CHASE)



This image of the sun's corona was obtained by a Solar Maximum Mission instrument.

Solar Ultraviolet High Resolution Telescope and Spectrograph (HRTS)

Dr. Guenter Brueckner
Naval Research Laboratory
Washington, D.C.

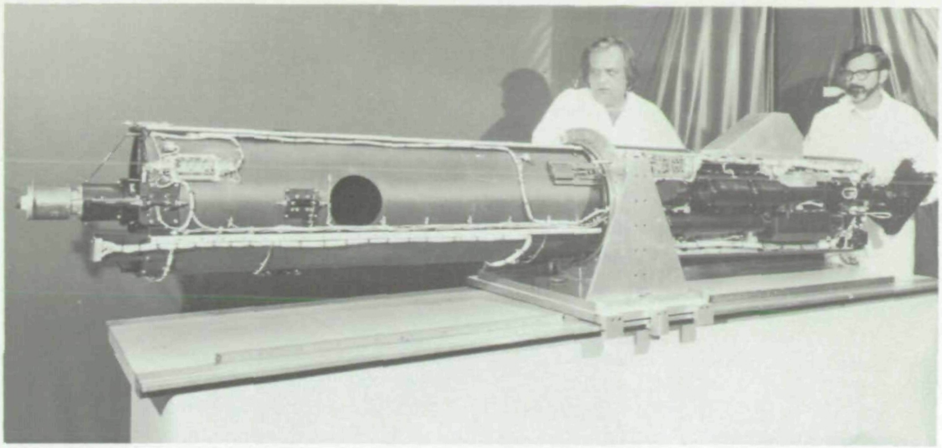
Purpose: This experiment studies features in the sun's outer layers: the chromosphere, the corona, and the transition zone between them.

Importance: The atmosphere of the sun is a stormy region of very high-speed "winds" of solar gases. The temperature of the solar atmosphere increases with altitude from about 6000° C in the visible photosphere to 10,000° C in the chromosphere and upwards to a million or more degrees in the corona. The areas of higher temperature emit copious ultraviolet radiation in the spectral band from 1200 Å to 4000 Å.

Analysis of spectral data tells scientists which elements are present, how they are distributed, and how they vary in temperature and density. In particular, spectral analysis of solar ultraviolet radiation gives insight into the physics of energy transfer through the sun's atmosphere. How are particles accelerated to very high velocities, and what mechanisms govern gas dynamics on the sun? These questions are fundamental to understanding the sun, and other stars as well.

One especially informative solar emission is a red line of hydrogen, called hydrogen-alpha, that occurs in the solar chromosphere. Although the sun has been observed in the light of hydrogen-alpha for more than 100 years, important discoveries are expected during Spacelab 2 because all hydrogen-alpha pictures from the ground are blurred by atmospheric turbulence. This investigation, for the first time, is producing high-resolution hydrogen-alpha pictures for long, uninterrupted intervals. These images should reveal new information about the movement of solar convective cells, called granules, which may play a major role in the heating of the outer solar atmosphere. Spacelab's unique capabilities allow investigators to obtain high-resolution observations of these and many other rapidly changing solar structures.

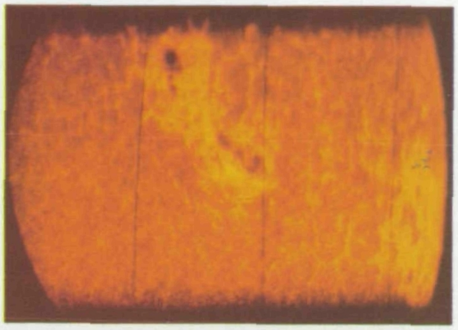
The High Resolution Telescope and Spectrograph (HRTS) experiment combines the advantages of ground-based solar observatories with those of space instrumentation. First, HRTS is large enough to make measurements equal or superior to those made by powerful telescopes on the ground. Because the Shuttle can carry very massive instruments, HRTS is larger than most satellite-borne instruments; it also benefits from the Shuttle-Spacelab advanced communication system that allows transmission of very high-resolution images. Furthermore, the HRTS telescope, unlike ground-based instruments, is not limited by atmospheric effects that filter radiation and distort images, nor is it idled by long nights. Aboard Spacelab 2, observations are interrupted only by a brief night portion of each orbit.



High Resolution Telescope and Spectrograph (HRTS)

Finally, experienced solar physicists working in space as Spacelab 2 payload specialists are available to interpret HRTS data and aim the telescope at targets of interest. It usually takes hours to point unmanned telescopes at specific solar features, and even then the observer may not know precisely where the telescope is aimed.

Method: The HRTS instrument includes a 30-centimeter (12-inch) telescope with a spatial resolution of one-half arc second (approximately 360 kilometers/223 miles on the solar surface). The telescope focuses a 4.5-centimeter (1.8-inch) solar image through the slit of a spectrograph, which then resolves the image into different wavelengths and records them on film.



A HRTS rocket image shows ultraviolet emissions at the base of the chromosphere where temperatures are lowest in the region. A sunspot is visible as the darkest area; intense yellow areas are active regions.

The spectrograph, the heart of the HRTS instrument, has many novel features. The most important is its capability to separate and record 2,000 distinct solar emission lines simultaneously and over a wide wavelength range. It can track solar gas moving as slow as 2 kilometers (1.2 miles) per second and as fast as several hundred kilometers per second. (Moving gas in the solar atmosphere can be distinguished from still matter because it emits light at slightly different wavelengths.) Observations are recorded on 36,000 film exposures, which can be taken as frequently as every seven-tenths second. Thus, HRTS can obtain images of rapidly changing solar structures, such as flares.

Additional focal plane instruments are a spectroheliograph and a hydrogen-alpha imaging system. The ultraviolet spectroheliograph photographs the solar image reflected from the front surface of the spectrograph slit; it detects carbon emissions from the solar transition zone, a region that is invisible from the ground.

Radiation detected by the spectrograph is also imaged in the light of hydrogen-alpha and recorded on film and video. The hydrogen-alpha video images are displayed on a television monitor in the aft flight deck. There, a payload specialist can scan the whole sun and select interesting viewing targets, such as sunspots or flares, and use the Instrument Pointing System to position the slit of the spectrograph properly. Hydrogen-alpha images are transmitted to the ground for analysis by investigative teams.

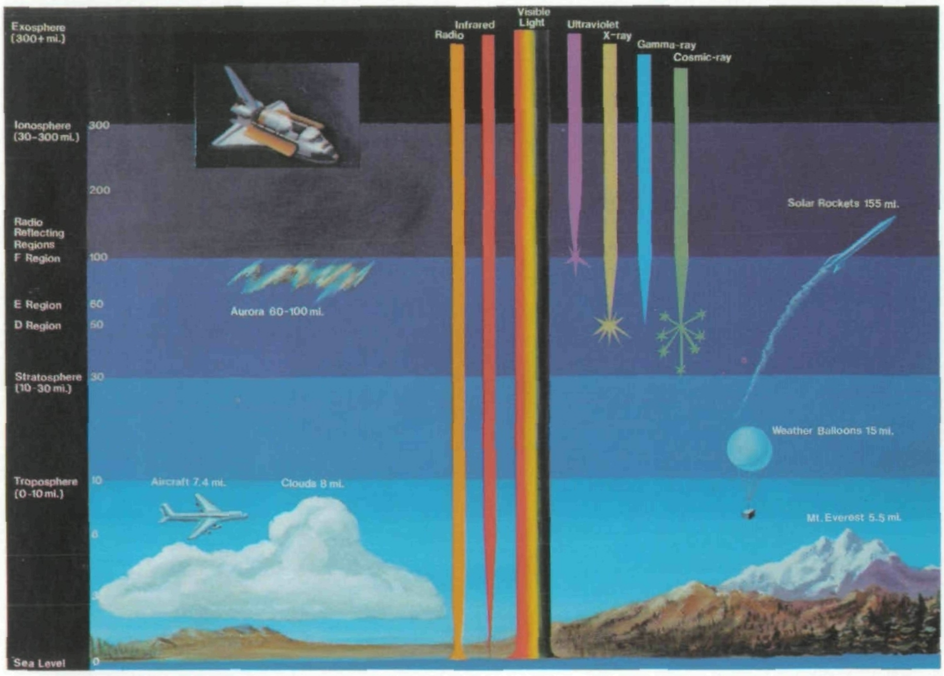
The main purpose of the HRTS investigation is to observe rapidly changing features in the solar chromosphere. Ultraviolet information on other solar structures can also be gleaned. Rocket flights of the HRTS instrument have revealed very high-velocity jets of matter spewing through the outer layers of the sun. These "coronal bullets" may be significant in understanding the solar wind that blows from the sun and past Earth with speeds of approximately 250 to 800 kilometers per second (150 to 500 miles per second).

Co-investigators for this experiment are Spacelab 2 payload specialist Dr. John-David F. Bartoe (who is also the project scientist), Kenneth R. Nicolas, and Michael VanHoosier, all of the Naval Research Laboratory; Dr. Eijiro Hiei of the University of Tokyo; Dr. Carole Jordan, of the University of Oxford in England; and Dr. Olav Kjeldseth Moe of the University of Oslo in Norway.

Atmospheric Physics

The Earth's atmosphere contains exactly the ingredients needed to support life. The atmosphere shields us from harmful objects, such as meteors, by destroying them before they reach the ground. It also blocks some harmful radiation, especially ultraviolet radiation from the sun.

Ultraviolet radiation exists just beyond visible light in the 250 Å to 3500 Å range of the electromagnetic spectrum. Only visible light and a small amount of infrared and ultraviolet radiation and radio waves from space reach Earth. Although ultraviolet radiation constitutes about 5 percent of the energy radiated by the sun, most of it is absorbed by the ozone layer in the stratosphere, an atmospheric region approximately 48 kilometers (30 miles) above Earth's surface. That which penetrates further is responsible for sunburn and other effects.



Earth's atmosphere is composed of several layers having distinct chemical and electrical properties.

Even though most ultraviolet radiation is absorbed in the upper atmospheric layers, it still has subtle, unexplained effects on our environment. It is speculated that changes in the total solar radiation may directly affect global weather and climate. Atmospheric physicists have already determined that solar ultraviolet radiation varies more than total solar radiation and, therefore, may be the key to weather fluctuations.

To measure ultraviolet radiation, scientists must place detectors above the stratosphere in the ionosphere, an upper atmospheric layer located from approximately 60 to 1000 kilometers (40 to 600 miles) above Earth's surface. Satellite-borne detectors in the ionosphere have not been able to measure ultraviolet flux for very long periods because the radiation itself gradually destroys the detector materials. The Shuttle-Spacelab allows investigators to fly an ultraviolet instrument for a while and then return it to Earth for recalibration before it becomes degraded.

One Spacelab 2 instrument was designed to measure solar ultraviolet radiation in the atmosphere. The instrument has two identical detector systems; one is used almost continuously to measure ultraviolet flux, and the other is used mainly to check the accuracy of the first detector's measurements. In addition, by scanning a known ultraviolet light source, the detector systems are calibrated in-flight. Upon return to the ground, the instrument can be checked again for degradation and be refurbished for future flights.

The instrument is scheduled to fly on several Spacelab missions to establish long-term variations in solar ultraviolet energy over an entire solar activity cycle, a period of about 11 years in which solar energy output peaks and declines. Besides obtaining a measurement of ultraviolet radiation, investigators may be able to connect energy fluctuations with specific solar events such as flares, the tremendous explosions that send matter hurling through space. Thus, this instrument complements the Spacelab 2 solar physics instruments and may provide new information on sun-Earth links.

Solar Ultraviolet Spectral Irradiance Monitor (SUSIM)

Dr. Guenter Brueckner
Naval Research Laboratory
Washington, D.C.

Purpose: The objective of this investigation is to determine both long-term and short-term variations of the total ultraviolet flux emitted by the sun.

Importance: Solar ultraviolet radiation in the wavelength range of approximately 1200 Å to 3000 Å is absorbed by Earth's upper atmosphere at altitudes between 20 and 120 kilometers (10 and 75 miles). Although this radiation constitutes only a small percentage of the total solar output, it is the main energy source for the upper atmosphere. Ultraviolet solar radiation plays a major role in the energy balance and chemical composition of the upper atmosphere, which in turn affects the lower atmosphere in which we live.

Scientists have already determined that solar ultraviolet radiation is more variable than is the total solar radiation. Present estimates of long-term solar ultraviolet variations are based on theoretical models and a few observations spaced far apart in time and made with different instruments. Systematic, high-precision measurements have never been carried out over a complete solar cycle. An accurate model of Earth's upper atmosphere must incorporate this variable solar input in its predictions of temperature, density and chemical composition.

The basic difficulty is that the same solar ultraviolet radiation being measured is also responsible for rapid degradation of the instrument making the measurement. As a result, photometers on board a satellite quickly lose their accuracy, and long-term solar effects cannot be distinguished from instrument changes.

The Solar Ultraviolet Spectral Irradiance Monitor (SUSIM) overcomes this problem by using new self-check calibration systems to determine whether instrument changes or solar flux variations are being recorded. The Shuttle's ability to carry SUSIM into space for a week and then return it allows preflight and postflight calibrations to determine instrument degradation. It also allows the instrument to measure ultraviolet radiation at several different times during the 11-year solar cycle.

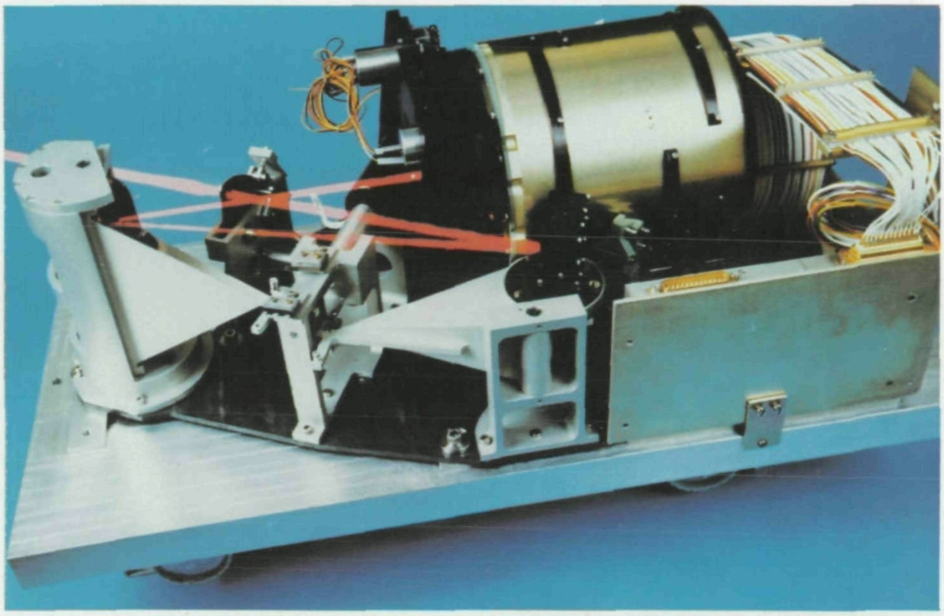
Method: The Solar Ultraviolet Spectral Irradiance Monitor specifically measures solar radiation in the ultraviolet wavelength range from 1200 Å to 4000 Å. SUSIM is operated automatically every time the Instrument Pointing System is aimed at the sun.

The instrument is equipped with redundant spectrometers and detectors to determine any change in its sensitivity during the solar exposure in orbit. One spectrometer is used during the daylight portion of each sun-pointed orbit to measure the variations in solar ultraviolet flux over the wavelength range with two different spectral resolutions (1.5 Å and 50 Å).

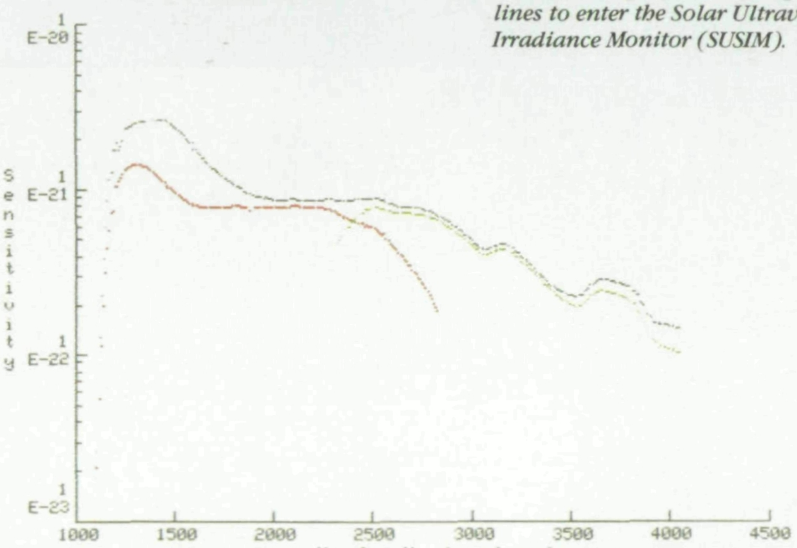
A deuterium lamp within the instrument serves as a calibration source. Once a day this ultraviolet lamp is turned on and positioned sequentially in front of each of the two spectrometers, which then scan its known ultraviolet spectrum to measure the instrument's sensitivity. Any of the seven detectors (two photon counters and five photodiodes) can then be used, with high accuracy, to compare the intensity of solar radiation with the intensity of the standard deuterium light.

SUSIM is not an imaging instrument; it provides high-quality data on total ultraviolet brightness and distribution. It is designed to fly as many times as possible during a solar cycle, preferably at least once a year, to monitor long-term solar ultraviolet fluctuations.

Co-investigators for this experiment are Spacelab 2 payload specialist Dr. John-David F. Bartoe, alternate payload specialist Dr. Dianne K. Prinz, and SUSIM project scientist Michael VanHoosier, all of the Naval Research Laboratory; and Dr. Stanley Shawhan of NASA Headquarters in Washington, D.C.



Ultraviolet light follows the path of the red lines to enter the Solar Ultraviolet Spectral Irradiance Monitor (SUSIM).



Earth's space environment

Plasma Physics

The atmosphere surrounding Earth is an oxygen-rich envelope of gases, vapors, and particles that filters harmful solar radiation and sustains life on our planet. Through ground-based measurements and studies from balloons, small rockets, and satellites, scientists have discovered that the atmosphere varies with altitude and has several regions with distinct compositions and physical properties. The Shuttle-Spacelab travels through a region of the upper atmosphere called the ionosphere. Extending from approximately 60 to 1,000 kilometers (40 to 600 miles) above Earth's surface, the ionosphere is a good place to study how different atmospheric layers are linked.

The ionosphere is a transition zone between the lower atmosphere in which we live and the magnetosphere, a volume of space dominated by Earth's magnetic field that shields the planet from energetic particles released by the sun. Scientists already know that all three atmospheric regions—the magnetosphere, the ionosphere, and the lower atmosphere—are influenced by an electrified gas or plasma, called the solar wind, that flows in space at speeds of a million miles per hour.

In the ionosphere, some elements exist as ions—atoms and molecules that have become electrically charged by losing or gaining electrons. This excited electrical state is maintained by the continual absorption of solar radiation. Disturbances in the electrical balance of the ionosphere can result in huge releases of electrical energy. For example, when beams of high-speed particles from the solar wind travel through the magnetosphere along magnetic field lines and strike particles in the upper atmosphere near Earth's poles, they are visible as auroras, the dazzling light shows known as the Northern and Southern Lights. A typical three-hour aurora discharges approximately 9,000 billion kilowatt hours of electric energy (9 times the annual U.S. consumption) into Earth's immediate environment. Auroras and magnetic storms may disrupt the transmission of radio and telecommunications signals through the ionosphere.

Plasma physicists want to define the complex physical and electrodynamic processes that produce these tremendous energy releases. Then, by monitoring changes in the ionosphere, they may be able to predict when a magnetic storm might disrupt radio communications or interfere with spacecraft electronics. In addition, because Earth's upper atmosphere resembles the plasma environments that exist around distant planets and stars, plasma processes common throughout the universe can be sampled and studied there.

Spacelab 2, which is immersed in plasma as the Shuttle orbits the globe, offers scientists a laboratory for conducting plasma physics experiments. The capability of the Shuttle-Spacelab to deploy satellites, expose instruments directly to space, and operate in coordination with ground-based facilities enables three Spacelab 2 plasma physics investigations to probe the ionosphere.

For one investigation, a small satellite contains a package of complementary instruments that simultaneously watch interactive physical processes in the ionosphere. During a previous Shuttle mission, plasma instruments on this satellite accurately measured magnetic and electrical fields, particle distributions, and radio waves as well as plasma composition, density, and temperature. During this mission, the remote manipulator arm is used to deploy the satellite as a free-flyer and later retrieve it and return it to the pallet. This is the first time that a satellite has been used for studying plasma regions away from the Shuttle. The satellite also makes measurements while mounted on the pallet and while moved around the orbiter by the arm.

A second investigation is an "active experiment" in which an electron beam from an electron generator is injected into the ionosphere to simulate natural events. From a pallet, plasma probes measure the nearby effects of the beam. Rather than wait for magnetic storms and related processes to occur naturally, scientists can create similar events for study by releasing particles under carefully controlled conditions. By observing the state of the plasma environment before, during, and after an artificial disturbance, they can gain insight into the conditions that naturally disrupt the atmosphere. The plasma satellite works jointly with this investigation by monitoring how the emitted electrons affect plasma regions at greater distances from the Shuttle. Part of the investigation is devoted to an attempt to generate low-frequency radio signals by pulsing the electron beam. Attempts to detect these signals will be made by ground-based and satellite receivers.

A third plasma physics investigation focuses on how the Shuttle itself affects the upper atmosphere. Firings from the orbiter's thruster engines produce exhaust, which is mainly water vapor. During similar exhaust releases by rockets, scientists discovered that the water vapor caused electrons to combine with ions in the upper atmosphere, leaving temporarily depleted plasma areas called "ionospheric holes." Since the ionosphere reflects radio signals between distant ground stations, scientists want to study the properties of the holes as well as their effects upon radio wave propagation. The Shuttle's ability to travel over prescribed locations and release exhaust at specific times allows scientists to carefully monitor these depleted plasma areas from ground-based observatories. In addition, probes on the plasma satellite can measure such changes in the ionosphere at close range.

Spacelab 2 is an orbiting plasma laboratory with instruments that work together in both passive and active experiments. By jointly probing the nature of the ionosphere and its links with the lower atmosphere, plasma physicists may find clues to atmospheric processes occurring around Earth and learn more about planetary atmospheres elsewhere.

Ejectable Plasma Diagnostics Package (PDP)

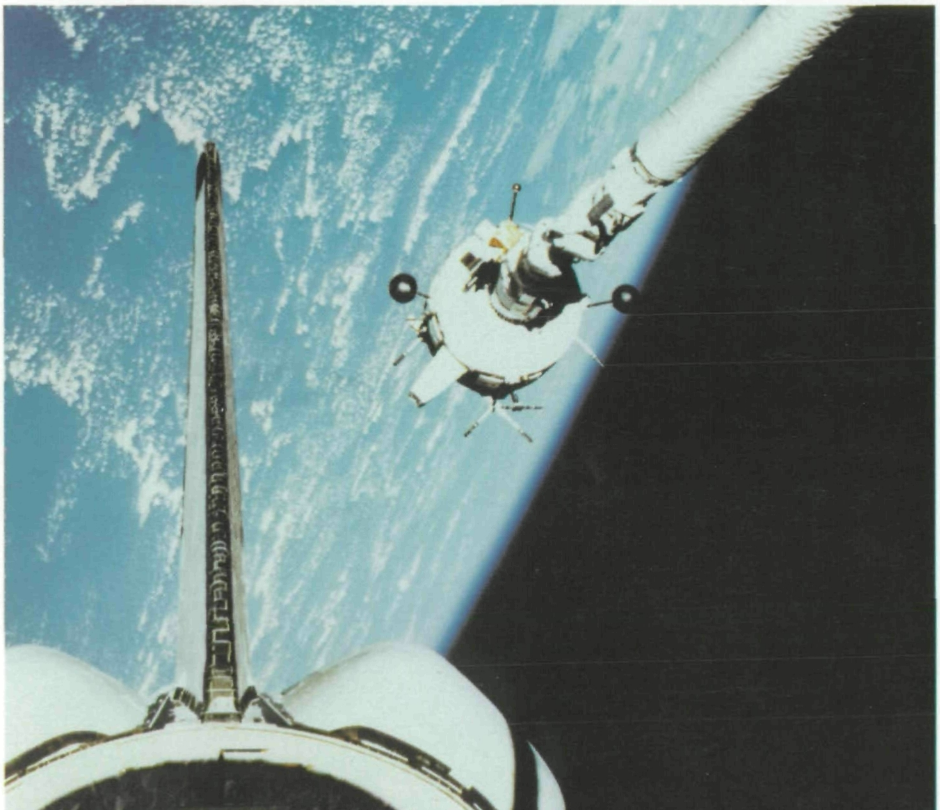
Dr. Louis A. Frank
University of Iowa
Iowa City, Iowa

Purpose: This investigation uses instruments on a subsatellite to study natural plasma processes, orbiter-induced plasma processes, and beam plasma physics.

Importance: Although the particles, gases, radiation, and fields that make up Earth's plasma environment are invisible, sensitive detectors can identify them and their characteristics. A better understanding of this complex environment can give us insight into processes occurring both in our atmosphere and in the atmospheres of other planets and stars.

Spacelab 2 is a platform from which instruments can directly measure the characteristics of the space plasma environment. Furthermore, the Shuttle itself can be used for the experiments because it disturbs the plasma, producing a dynamic wake as it travels. This wake, which is similar to that created in water by a boat, may alter the total electron density and temperature in the plasma. Charges may build up on the orbiter's insulated surface or a current may be conducted by uninsulated parts of the orbiter. For better understanding, these complex interactions must be examined by instruments that can be placed outside the Shuttle.

Spacelab 2 is the second flight of the Plasma Diagnostics Package, which operated successfully during the third Shuttle mission. On its first flight, the subsatellite made measurements while mounted in the Shuttle payload bay and while suspended from the manipulator arm. It successfully measured electromagnetic noise created by the Shuttle and detected other electrical reactions taking place between the Shuttle and the ionospheric plasma. During this mission, the satellite makes additional measurements near the Shuttle, and for the first time it is released as a free-flyer to sample plasma more than a quarter-mile away from the Shuttle.



During the third Shuttle mission, the plasma diagnostics package studied the upper atmosphere while attached to the remote manipulator arm.

Method: Fourteen instruments are mounted on the Plasma Diagnostics Package (PDP) subsatellite for measurements of various plasma characteristics, such as low-energy electron and proton distribution, plasma waves, electric field strength, electron density and temperature, ion energy and direction, and pressure of uncharged atoms.

The PDP can operate on its own or jointly with two other experiments for enhanced scientific results. In another plasma experiment to stimulate the environment with an electron beam, the PDP measures how artificially-accelerated particles react with atmospheric particles. In an experiment that studies "holes" in the plasma, the PDP instruments measure the characteristics of plasma-depleted areas while ground observatories make similar observations with radar and cameras.

Throughout the flight, the PDP instruments study the natural plasma environment from the aft pallet, detecting changes in electric and magnetic field strengths as different instruments are turned on and monitoring the electromagnetic interference created by the Shuttle. These measurements should complement data collected on the third Shuttle mission.

On the second day, the crew executes an elaborate set of simultaneous operations. The Shuttle flight crew maneuvers the orbiter to specific attitudes while the mission specialist uses the robot arm to pick up the PDP and move it to specific orbiter locations. The remote manipulator arm can turn the PDP to point the various plasma instruments in the precise directions necessary for the most accurate data acquisition. Measurements from the previous mission indicate that precise pointing is necessary for individual instruments to perform well.

One purpose of these experiments is to gain more data on the orbiter's environment. During the PDP's last flight, data re-

vealed noise from particle interactions (electromagnetic interference) everywhere in the payload bay. Investigators want to further define the possible sources of the interference, which can disrupt the operation of certain instruments or cause them to make inaccurate readings. During this mission, the plasma instruments make a complete set of measurements around the orbiter's transmitters and radar to determine their role in this process.

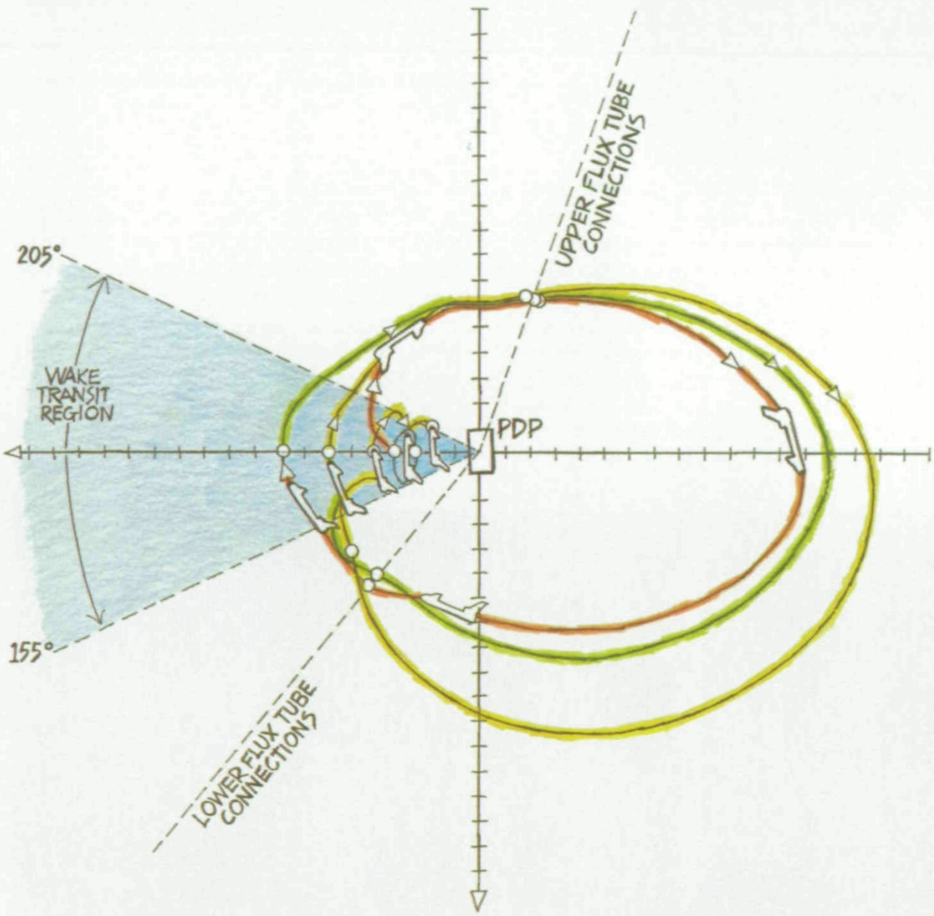
Another purpose of these maneuvers is to determine more accurately the cause of "Shuttle glow," which is apparently caused by a strong interaction between the orbiter and surrounding plasma. A better definition of the phenomenon is needed for a better understanding of the ionosphere and its effect on large spacecraft. Therefore, the plasma diagnostics instruments are brought within 2 meters (6.6 feet) of the Shuttle wings and cockpit to examine plasma reactions near orbiter surfaces. In addition, the PDP is placed in the field of view of an infrared telescope capable of measuring hydrogen, oxygen, nitrogen or other elements that may be involved in the glow reaction. Meanwhile, the orbiter is moved into different attitudes to investigate relationships between the glow and the orbiter's direction of travel.

In another experiment, the PDP can be placed near vehicle surfaces to measure changes in the Shuttle's electrical charge as a generator emits an electron beam. This beam automatically follows the invisible magnetic and electric fields surrounding the Shuttle. By measuring the beam's characteristics, the plasma instruments also gather information about fields and particles in the nearby environment.

The most intricate PDP experiments are scheduled for flight day three. The PDP is released by the robot arm, and the orbiter begins an elaborate sequence of maneuvers called a "fly-around." After the arm releases the PDP, a momentum wheel spins the satellite at 5 rpm to fix it in a stable enough position for accurate measurements. As the orbiter moves away slowly to a distance of approximately one-half kilometer (one-third mile), the PDP studies the natural plasma environment away from the Shuttle. This is the first time that ambient plasma has been sampled so far from the Shuttle. The plasma survey will help investigators determine how far the orbiter's effects extend. As the Shuttle flies in specific trajectories around the PDP, the plasma environment is sampled all around the orbiter.

In one important experiment, the Shuttle and the plasma satellite are lined up along the same magnetic field line much like beads on an imaginary string. This link between the orbiter and the PDP is called a "flux tube connection" because disturbances created by the vehicle automatically flow along the magnetic field line. Such disturbances as electrostatic noise (a broad band electrical hiss) should flow from the orbiter toward the plasma instruments, which can study changes in the noise. The PDP can also study and measure the distance of the wake created as the Shuttle moves through the ionosphere. The Shuttle is a very large object that creates vast plasma disturbances; this effect could never be simulated in an Earth-based laboratory.

During this mission, the plasma diagnostics satellite operates independently away from the Shuttle to study a greater area of the space plasma environment.



During the fly-around, the PDP also performs some joint experiments with the electron generator used in another plasma physics investigation. When the Shuttle and the PDP are lined up along the same magnetic field line, an electron beam emitted by the generator should flow along the field line toward the PDP. The plasma instruments measure the characteristics of the beam as it spreads into the ionospheric plasma. These measurements can be compared to those made earlier at close range to the beam, when the PDP was placed near the orbiter's surfaces. In addition, when the electron beam is pulsed to create small currents, the PDP measures the plasma waves created by the currents. Because the ionospheric plasma interferes with normal low-frequency antenna operations at this altitude, this experiment may help determine whether a pulsed electron beam can be used as a low-frequency radio signal antenna.

After the fly-around is complete, a preset timer inside the PDP stops its spinning motion, and the Shuttle maneuvers close to it. The arm plucks it out of space and holds it over the wing where it can continue to make measurements of the near-Shuttle plasma environment. Before reentry, the arm returns the PDP to the aft pallet where it is anchored for landing.

Co-investigators for this experiment are Dr. Nicola D'Angelo and Dr. Donald A. Gurnett, both of the University of Iowa; Dr. Joseph Grebowsky of Goddard Space Flight Center in Greenbelt, Maryland: and Dr. David L. Reasoner and Dr. Nobie H. Stone, both of Marshall Space Flight Center in Huntsville, Alabama. PDP project scientist is Dr. William S. Kurth of the University of Iowa.

Vehicle Charging and Potential Experiment (VCAP)

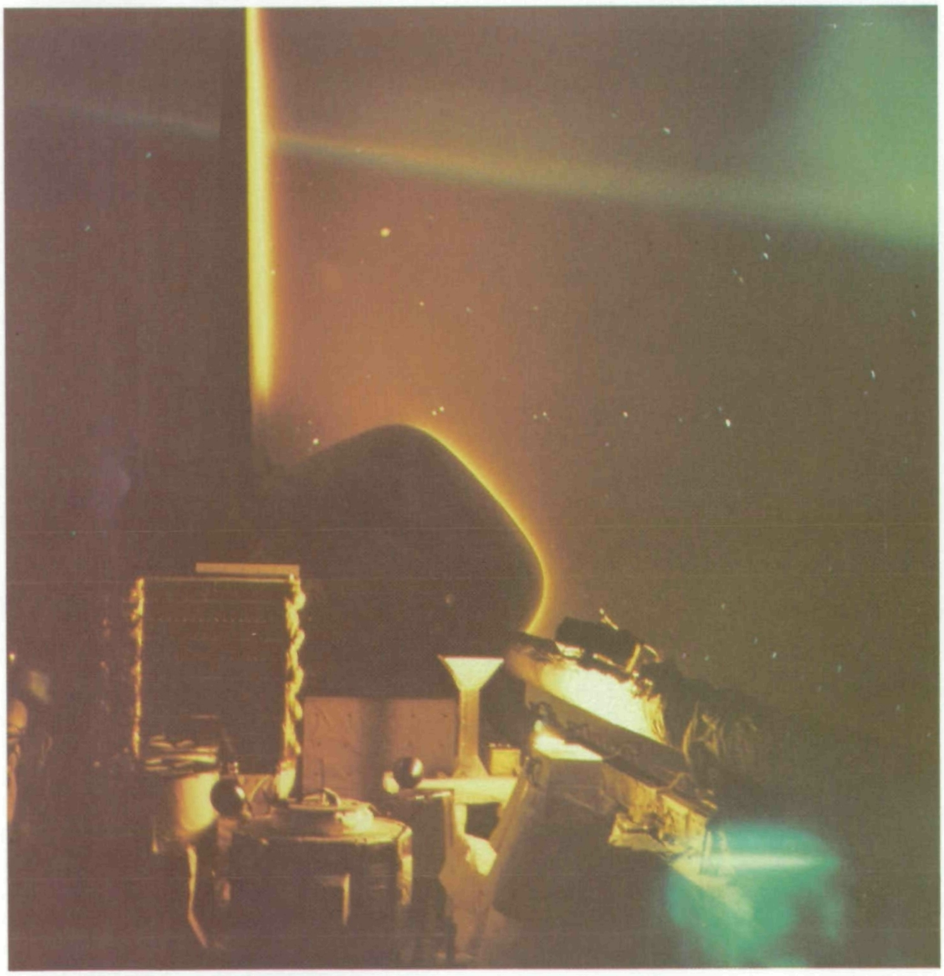
Dr. Peter M. Banks
Stanford University
Stanford, California

Purpose: This investigation's goal is to study the ionosphere's natural traits by perturbing it with beams of electrons.

Importance: The Vehicle Charging and Potential (VCAP) investigation is an "active experiment" that uses the ionosphere as a natural laboratory. Many physical processes in the ionosphere are unexplained, and active experiments can be used to trace natural phenomena or to induce phenomena artificially. By performing active experiments in space, investigators can introduce into the ionosphere a known stimulus and measure the environment's response.

Plasma physicists are interested in the high-energy processes that occur during magnetic storms and auroras. Beams of particles from the sun travel along Earth's magnetic field and strike the upper atmosphere, where they are visible as brilliant auroral light. Auroras sometimes disrupt communications, navigation, and power transmission. Typically, scientists have to wait for an aurora to occur naturally in order to study it; then, analysis of plasma processes is difficult because incoming particles and energy cannot be measured precisely. Attempts to simulate the process in ground-based labs are inadequate because laboratory walls interfere with plasma flows.

Now, by performing active experiments in the vast open laboratory of the ionosphere, investigators can carefully create processes that may be similar to natural ones. Instead of waiting for nature to perform, they can create auroras and thus determine more precisely the environmental conditions before, during, and after a disturbance. To imitate the auroral process under controlled conditions, Spacelab 2 scientists generate and accelerate electron beams through the atmosphere. Probes in the Shuttle payload bay and the Plasma Diagnostics Package (PDP) monitor the resultant chemical and electrical processes as the beams are emitted.



The glow along the edge of the Shuttle is thought to be the result of ions interacting with the vehicle's surfaces. This photograph was taken on the third Shuttle mission as part of the VCAP experiment.

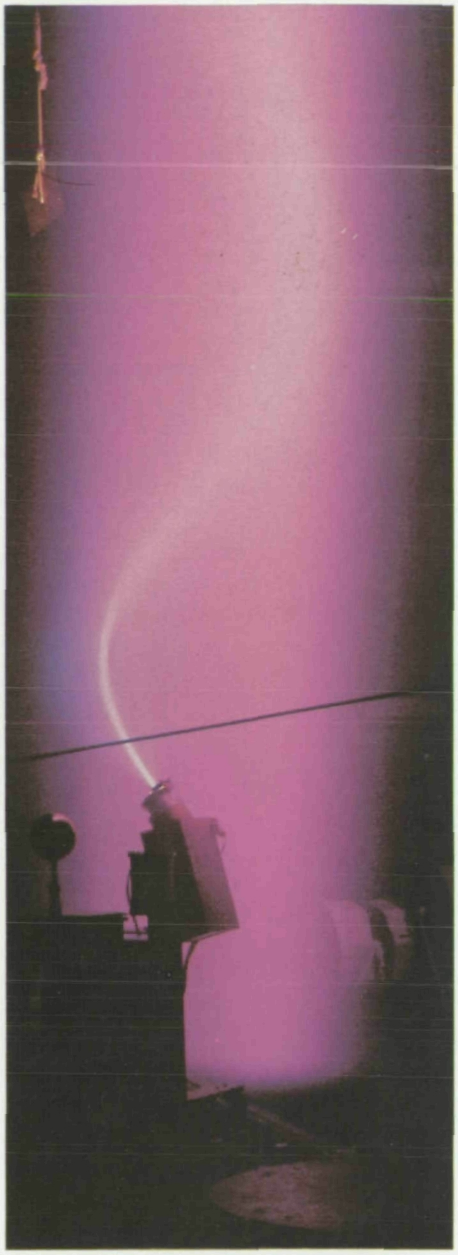
In addition to mimicking natural phenomena, the charged particles produced by the experiment follow the magnetic field. Unseen magnetic field lines are manifested in streaks of color as the artificial particles interact with the ionospheric plasma. Scientists can then watch and photograph the trajectories of these particles as they stream along the magnetic field.

Plasma physicists are also interested in the way energy is transferred from one atmospheric region to another, where it may be deposited, absorbed, or transformed and carried elsewhere. One energy transfer mechanism appears to be "waves" that are generated naturally in the atmosphere by the constant mixing and flowing of plasma and by sudden disturbances, such as electrical storms. VCAP electron beams injected into space create similar waves. Study of the propagation patterns and changes in frequency of waves will lead to a better understanding of energy exchange processes in the upper atmosphere.

Wave experiments also address space technology problems in antenna design and efficiency. Designers have not been able to develop an efficient low-frequency space antenna because the ionospheric plasma interferes with transmissions. By pulsing the electron beam at different frequencies, VCAP investigators can create currents that act as an antenna to carry radio waves. In a related study, transmissions sent via a Spacelab ham radio can be monitored to see where and at what frequency the radio waves are propagated. These completed transmissions may give investigators insight into the behavior of radio waves in the upper atmosphere. Analysis may influence the design of more efficient antennas or an entirely new method of communications.

The VCAP experiment operated successfully during the third Shuttle mission. During the Spacelab 2 mission, more sophisticated research can be performed based on information from the previous flight, and first-time studies of beams at great distances from the Shuttle can be attempted.

Method: The Vehicle Charging and Potential investigation uses four instruments. An electron generator, mounted on the first pallet, emits electrons in a steady stream or in pulses of varying durations. It is pointed perpendicular to the orbiter payload bay, but electron emissions will spiral along the magnetic field lines. By calculating the posi-



An electron beam emitted from an accelerator spirals around an invisible magnetic field line in a NASA plasma chamber. The purple glow is nitrogen gas ionized and excited by the beam.

tion of the magnetic field at a given time, investigators can control the direction of the electron beam. The electron generator has two ports; one emits electrons at a current of 50 milliamps and the other at 100 milliamps. (A milliamp equals one-thousandth of an ampere.) The maximum power of the electron beam that can be emitted is approximately equal to the power generated by a 100 watt light bulb. The ports can generate electrons separately or simultaneously.

Three plasma probes mounted on a shelf on the second pallet are used to measure the effects induced by the emitted beam. A current probe, with a gold-plated metal surface that is similar to conducting surfaces on the Shuttle, measures the total current flowing to it after a beam emission. A charge probe, covered with insulation that is similar to the orbiter's insulation, measures the total charge deposited on the insulated surface. Charges and currents flowing to these two probes should be similar to those on Shuttle surfaces. A spherical probe measures the absolute vehicle electrical potential and ion densities and temperatures. A microprocessor collects information from the probes and electron generator and transmits it to the crew or to scientists in the Payload Operations Control Center.

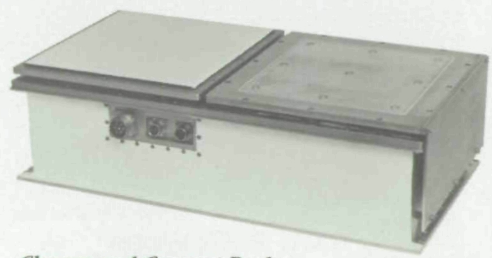
Some VCAP experiments are performed jointly with the Plasma Diagnostics Package. As a Spacelab 2 payload specialist commands the electron generator to emit a steady stream of electrons, a mission specialist uses the remote manipulator system to move the PDP through the electron beam. The plasma instruments can measure any strong reactions that may be changing electron energies, and the data may give insight into electron interactions during high-energy processes, such as auroras. The dimensions of the beam and the behavior of electrons as they are accelerated can also be measured.

The crew members carefully control the beam emissions when the PDP is released approximately one-half kilometer (one-third mile) from the Shuttle. During this experiment sequence, investigators study a beam at a distance from the Shuttle for the first time. In one experiment, the orbiter and the PDP are lined up along the magnetic field so that a particle beam should follow the field line to the diagnostics package. Investigators are eager to see if the beam extends all the way to the PDP. By studying the shape of the beam, they may find clues to some of the many puzzles of electron beam propagation. Do the electrons follow a predicted path or do they scatter at large distances? Do they change energies as they interact with the surrounding plasma? How fast does the intensity of the electron beam change with distance?

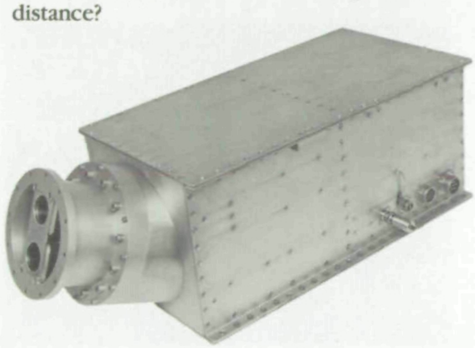
In another experiment, crew members command the generator to turn the beam on and off quickly, which results in the production of radio waves at very low frequencies. If these radio waves reach the PDP, the pulsed electron beam may be an efficient antenna for low-frequency radio waves. Radio patterns around the Shuttle also can be examined.

Crew members use a special television camera that intensifies light to photograph the electron beam as it moves along invisible magnetic field lines. By calculating the magnetic field location at a particular orbiter position, investigators on the ground can command the generator to produce electrons that follow the field to a specific part of the orbiter, such as the tail. This experiment may create a bright enough particle reaction that the electron beam (and thus the geometry of the magnetic field) and the glow on Shuttle surfaces can be photographed.

Co-investigators for this experiment are Dr. Kay D. Baker and Dr. W. John Raitt, both of Utah State University in Logan, Utah; Dr. Nobuki Kawashima and Dr. Tatsuzo Obayashi, both of the Institute of Space and Astronautical Sciences in Japan; and Dr. P.R. Williamson of Stanford University.



Charge and Current Probes



Electron Generator

Spherical Probe

Plasma Depletion Experiments for Ionospheric and Radio Astronomical Studies

Dr. Paul A. Bernhardt
Los Alamos National Laboratory
Los Alamos, New Mexico

Dr. Michael Mendillo
Boston University
Boston, Massachusetts

Purpose: This investigation uses the Shuttle as an active experimental probe to create artificial "holes" in the ionosphere. At the same time, ground-based observatories use radio and optical observing techniques to study the plasma characteristics of the holes and to conduct radio astronomical studies through them.

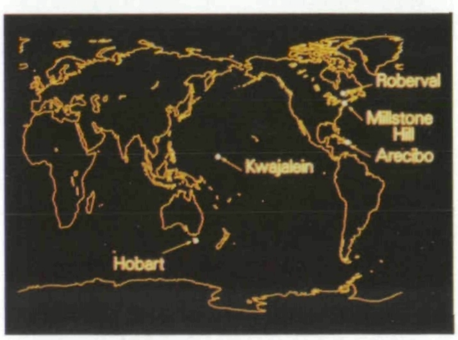
Importance: The Shuttle travels through the ionosphere, a region of Earth's upper atmosphere where solar radiation transforms atmospheric atoms into electrically conducting ions and electrons. Variations in the ionosphere occur on a day-to-day basis as well as during large solar flares and geomagnetic storms.

During the Skylab launch by a Saturn V rocket, scientists discovered that the total electron content of the ionosphere was reduced 60 percent over an area 1,000 kilometers (600 miles) in radius for two to four hours. The depletion occurred because neutral gases (hydrogen and water molecules) contained in the Saturn V exhaust plume caused the ambient ions and electrons to recombine at an exceptional rate, reducing the ambient plasma density and forming an "ionospheric hole."

The Shuttle thrusters can be fired at specific times during flight to produce the same effect. These exhaust gases cause plasma to exhibit characteristics that can be detected by radar and other instruments at ground observatories. For example, electron concentrations are reduced, electron temperature rises, atmospheric airglow is enhanced, and radio wave propagation is affected.

Some radio waves transmitted from astrophysical objects are blocked by the ionosphere. This is particularly true for low-frequency waves near the AM radio band. Like other forms of radiation from space, radio energy gives insight into the composition of the universe. Astronomers in observatories on the ground want to try to perform low-frequency radio studies through the artificial ionospheric holes. These studies could demonstrate how the depleted plasma affects radio wave propagation and whether or not it opens a window to radio signals from astronomical sources.

The Millstone Hill facility at the Haystack Observatory (right) and Boston University's Mobile Ionospheric Observatory (left) study plasma depleted areas resulting from Shuttle engine burns. The mobile unit contains a low-light-level imaging system to record the enhanced atmospheric airglow.



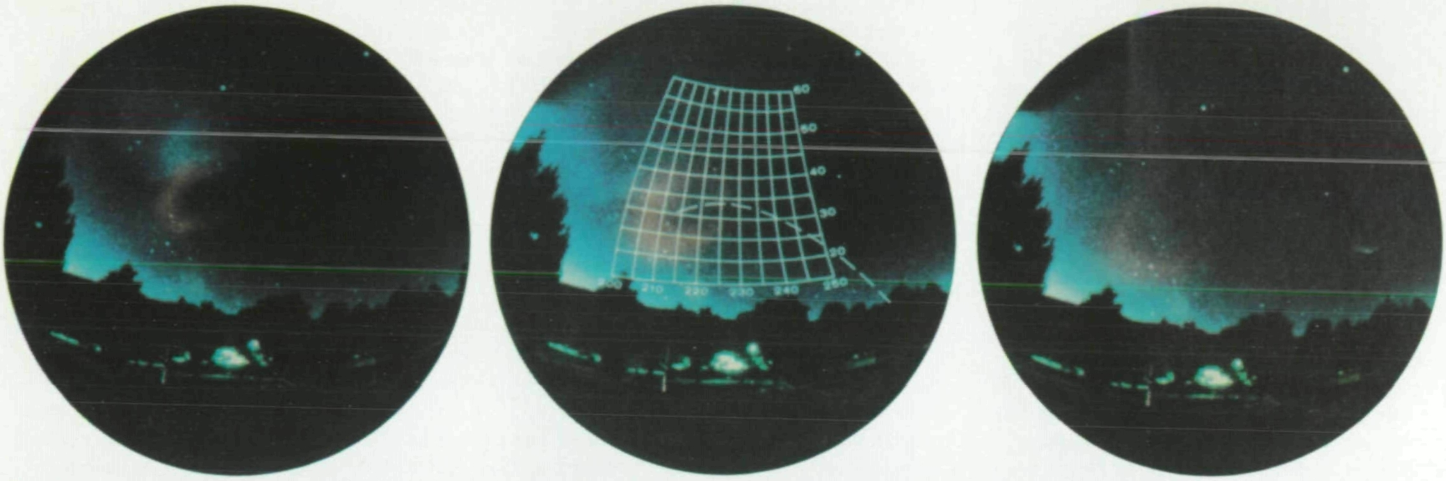
Designated ground observatories study the characteristics of ionospheric holes.

Method: Shuttle thruster firings are made over prescribed ground sites to release from 130 to 1,300 kilograms (300 to 3000 pounds) of exhaust vapors, consisting primarily of water. During the exhaust releases, scientists at ground-based observatories watch for the appearance of resultant "holes" in the ionosphere. Five participating radio observatories were selected for their location and available instrumentation: the Millstone Hill Incoherent Scatter Ionospheric Observatory in Westford, Massachusetts; the Stanford University Very Low Frequency (VLF) facility in Roberval, Quebec (Canada); the National Astronomy and Ionospheric Center in Arecibo, Puerto Rico; the ALTAIR incoherent scatter radar in the Kwajalein Atoll (Marshall Islands) in the Pacific Ocean; and the University of Tasmania and Reber Observatories in Hobart, Tasmania (Australia). A self-contained observatory in a van, the Boston University Mobile Ionospheric Observatory, was created especially for this mission to monitor the ionosphere from various locations near the Millstone Hill Observatory.

High to midlatitude ionospheric hole measurements are to be conducted from the Millstone Hill Observatory. During a major daylight engine burn required to raise the Shuttle to its maximum altitude on this mission, a 46-meter (150-foot) steerable antenna measures changes in the number of electrons, plasma drift, and plasma temperatures. During an engine burn at night, photometers, low-light-level television, and image-intensifier cameras are used to record airglow changes associated with the hole. During another daytime engine burn over Roberval, major changes in the plasma temperatures are recorded by the Millstone radar.

The Arecibo observatory uses its 300-meter (1,000-foot) diameter radar to measure changes in electron density, ion composition, and electron and ion temperatures after two similar low-latitude thruster firings, one at night and one during daylight. Intensified cameras also record images of enhanced airglow clouds created by the night-time release.

Shuttle thruster firings over Roberval allow scientists to study the transmission of very low frequency radio signals between



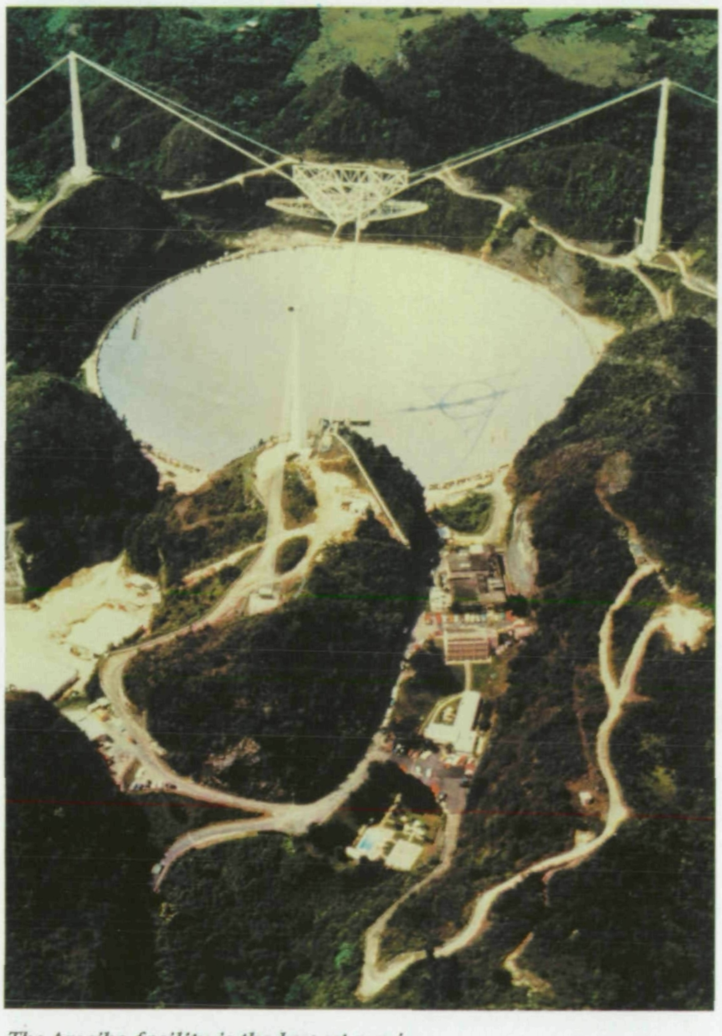
Roberval and Siple Station, Antarctica, to see the effect of the plasma-depleted area on VLF propagation. During the engine burns over Roberval, the Plasma Diagnostic Package and the Millstone observatory study ionospheric holes simultaneously for the first time. While on the robot arm, the Plasma Diagnostic Package samples the affected region one orbit (90-minutes) after the engine burns near Roberval.

The Kwajalein Atoll observatories are located near the geomagnetic equator where ionospheric holes tend to rise because of plasma instability effects. This makes Kwajalein an interesting location for studying the shape and structure of ionospheric holes as compared to more stable regions. Both radar and airglow observations are made at Kwajalein.

Low-frequency radio astronomical observations through the depleted ducts in the ionosphere are made at the University of Tasmania. Scientists there use large ground-based antennas to obtain high-resolution observations in the 1 to 5 MHz range from different regions of the galaxy and to study several radio sources in the low-frequency domain. If they can look through these ionospheric windows and see the galaxy in radio waves more clearly, a new technique for astronomical observations may be born. Investigators also study the characteristics of the ionospheric plasma during the Hobart engine burn.

Co-investigators for this experiment are Dr. David Anderson and Dr. Edward Weber of the Air Force Geophysics Laboratory in Bedford, Massachusetts; Dr. Doran J. Baker and Dr. Ronald Harris, both of Utah State University in Logan, Utah; Dr. G.R.A. Ellis of the University of Tasmania in Hobart, Tasmania (Australia); Dr. Donald Farley and Dr. Michael Kelley, both of Cornell University in Ithaca, New York; Dr. Robert A. Helliwell of STAR Laboratory in Stanford, California; Dr. William Oliver of the Haystack Observatory in Westford, Massachusetts; Dr. Michael Papagiannis of Boston University; and Dr. Morris Pongratz of Los Alamos National Laboratory.

The swirl of red atmospheric airglow is a result of reactions triggered by exhaust vapors from an ATLAS rocket.



The Arecibo facility is the largest semi-steerable radio/radar observatory on Earth.

High Energy Astrophysics

The universe is an astrophysical laboratory where mixtures of tenuous gas and atomic particles condense under gravity and electrical forces to form stars and galaxies. Before the invention of rocketry, we could study only the visible images of the universe. As we moved beyond Earth's filtering atmosphere, first with instruments on balloons and then on sounding rockets and satellites, the heavens began to look quite different.

Much of our recent knowledge about the cosmos is obtained via ultrasensitive instrumentation in space. Modern observations reveal violent, high-energy events associated with the birth and death of stars. We now witness a volatile universe in which particles are accelerated to velocities approaching the speed of light and heated to extreme temperatures. These processes result in emissions of X-rays, gamma rays, and nuclear particles.

One goal of high-energy astrophysics is to examine this energetic radiation and to interpret the message it bears about the past and continuing development of the cosmos. During Spacelab 2, the origin and nature of the explosive energy produced in stars and galaxies is studied through analysis of X-rays and high-energy charged particles called cosmic rays.

X-ray emissions occur when gases are heated to very high temperatures, and electrons and protons are accelerated to energies between 100 and 100,000 electron volts. By comparison, visible light is imparted in energies of two to three electron volts. Various physical processes are responsible for X-ray emissions.

X-ray astronomy, the study of physical processes associated with X-ray emissions from celestial objects, is a new discipline. The first X-ray source outside the solar system was discovered in 1962 during a 5-minute flight of an X-ray detector aboard a small rocket. However, such flights were too brief for studying sources in sufficient detail to understand the complex physics responsible for such powerful emissions. After the pioneering missions of small satellites, such as Uhuru in the early 1970's, the first detailed studies and extended surveys of the X-ray sky were made in the late 1970's by three High Energy Astronomy Observatories (HEAO). It is now the goal of X- ray astronomers to study X-ray sources in much more detail.

The Shuttle-Spacelab is a vehicle designed to carry heavy instruments above the atmosphere. Thus, it is an ideal platform for very sensitive, large telescopes needed for X-ray astronomy, such as the Spacelab 2 X-ray telescope. This instrument is dedicated to the detailed study of X-ray emissions from clusters of galaxies.

Groups of stars form galaxies, and galaxies themselves congregate in clusters of approximately 100 to 1,000 members. Clusters are grouped in superclusters, which are the largest aggregates of matter in the cosmos. This clustering probably reflects conditions at the time of galactic formation, but little is known about how individual galaxies have evolved.

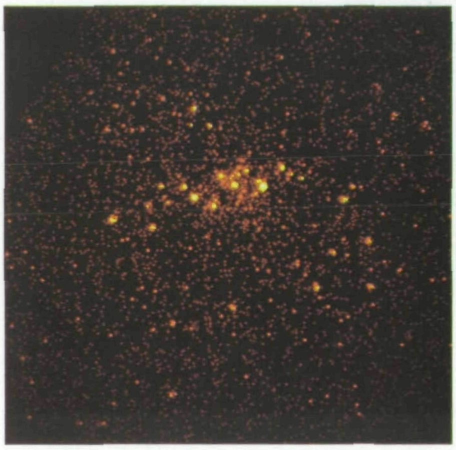
Galaxies in a cluster are bathed in a huge cloud of gas so hot that it can only be studied by an X-ray telescope. This gas may influence galactic evolution. Until now, the only detailed studies of the intergalactic gas have been made in lower energy "soft" X-rays, which tend to radiate from cooler galactic gas. Spacelab 2 provides the first opportunity to extend these studies to "hard" X-rays, which are more energetic and tend to radiate from much hotter gas. By studying these strong emissions, investigators hope to obtain more detailed information on clusters of galaxies.

Cosmic rays are another form of high energy astronomical radiation. In fact, the most energetic cosmic rays carry by far the largest energy found in a single particle or light photon anywhere in the universe. Cosmic rays are composed of atomic nuclei, mostly hydrogen but also a mixture of all the other known chemical elements. They probably gain their enormous energies during explosive events.

In spite of their energy, cosmic rays cannot penetrate Earth's atmosphere without being broken up into showers of secondary particles. Thus, observations must be performed on high-altitude balloons or in space. Often balloons cannot travel quite high enough for maximum exposure to cosmic rays or cannot stay aloft for a sufficiently long time. Therefore, instruments on spacecraft orbiting Earth at higher altitudes are best suited for studying the highest energy cosmic rays.

There has not yet been an opportunity for space-based research with an instrument large and sensitive enough to collect detailed information on the quite rare particles at energies beyond 100 billion electron volts. The Shuttle's weight-carrying capability makes it possible to do this for the first time during the Spacelab 2 mission.

In order to fly the most sensitive detector with the largest possible collecting area, investigators designed the innovative Spacelab 2 cosmic ray instrument with a low-weight plastic detector instead of the usual heavy metal version. At the heart of the instrument are two types of detectors, keyed to two specific particle energy ranges. As the particles penetrate the detectors, they release electrical pulses that are "fingerprints" of their identities and energies. From the data, physicists can identify each individual particle that penetrates the instruments as an element (e.g., oxygen, nitrogen, carbon, iron), and they can measure the particle energy in a range that could never before be explored. Scientists hope that these measurements will yield important information on the nature of the particle sources, the methods of particle acceleration, and the properties of the interstellar medium through which particles travel.



Viewed in visible light (left), the center of the Andromeda Galaxy appears as a bright cloud of gas. When imaged in X-rays (right), the galaxy is revealed as a collection of many X-ray sources.

Elemental Composition and Energy Spectra of Cosmic Ray Nuclei Between 50 GeV/ Nucleon and Several TeV/Nucleon

Cosmic Ray Nuclei Experiment (CRNE)

Dr. Peter Meyer
Dr. Dietrich Müller
University of Chicago
Chicago, Illinois

Purpose: The objective of this investigation is to study the composition of high-energy cosmic rays by using a large instrument exposed to space for a considerable period of time.

Importance: Particles accelerated by astrophysical explosions arrive at Earth in the form of cosmic rays, atomic nuclei traveling at almost the speed of light. Detecting these high-energy particles and determining their composition and energies would help scientists to identify their sources, understand better the violent events occurring elsewhere in the universe, and understand how it is physically possible to accelerate matter to such high energies.

Previous experiments have shown that the composition of cosmic rays varies as their energy changes. These variations not only suggest the sites where cosmic rays originate but also provide information on the time that they have spent in the galaxy. Since magnetic fields are believed to be responsible for retaining the particles in the galaxy, composition measurements at high energies also help scientists understand the magnetic field structure of the galaxy.

To detect a rare cosmic ray, one needs to expose a large detector for a long time beyond Earth's atmosphere. Past experiments were limited by small instruments, brief exposure time, and a narrow range of measured energies. This experiment, however, takes advantage of the Shuttle's capability to carry a massive instrument into space. Weighing 1,968 kilograms (4,330 pounds), the cosmic ray detector is the largest scientific instrument to be transported by the Shuttle-Spacelab. This huge detector can study cosmic ray composition to energies almost 100 times greater than those previously studied.

Method: Cradled by a special support structure at the end of the Spacelab pallet train, the cosmic ray detector is exposed to space during the entire seven-day mission. The egg-shaped instrument shell is filled with layers of detectors. Particles enter through both ends of the instrument, but only those entering the space-exposed end are measured.

The chemical identity of each incoming cosmic ray nucleus is determined by examining the energy it loses in two scintillation counters located in the midsection of the detector. These counters contain a special plastic that produces a light flash which increases in intensity as the particle's nuclear charge increases. The light is detected and converted to electrical signals by photomultipliers.

Investigators used a novel design and lightweight materials to construct the largest cosmic ray detector ever to fly in space.

Gas Cerenkov devices are located in both ends of the instrument; these detectors, filled with nitrogen and carbon dioxide, measure the energies of cosmic rays between 40 and 150 billion electron volts (GeV) per atomic particle (nucleon). As a particle enters the gas volume, it creates an electromagnetic shock wave, similar to a shock wave produced in air by a supersonic jet plane. A burst of light inside the detector is converted into electrical pulses by photomultipliers.

Ultra-high energies between 400 and 4,000 GeV per nucleon are measured with a transition radiation detector spanning the midsection of the instrument. This detector consists of a stack of radiators alternating with multiwire proportional chambers filled with a xenon, helium, and methane gas mixture. The gases optimize the signal strength from the X-rays produced by particles penetrating the radiator. The radiators are made of polyethylene fibers, used for the first time in this experiment because they work as well as conventional foil radiators and are far easier to fabricate into large, lightweight units.

All the sensors send data directly to an electronics package for transmission to the ground. The cosmic ray detector operates continuously throughout the mission and requires little crew attention.

Co-investigators for this experiment are Dr. Jacques L'Heureux, James E. Lamport, and Dr. Simon P. Swordy, all of the University of Chicago.

Co-principal investigators Dr. Peter Meyer (above) and Dr. Dietrich Müller (below) in the laboratory where the cosmic ray instrument is being built. The complex detectors are visible in the background of the photographs.

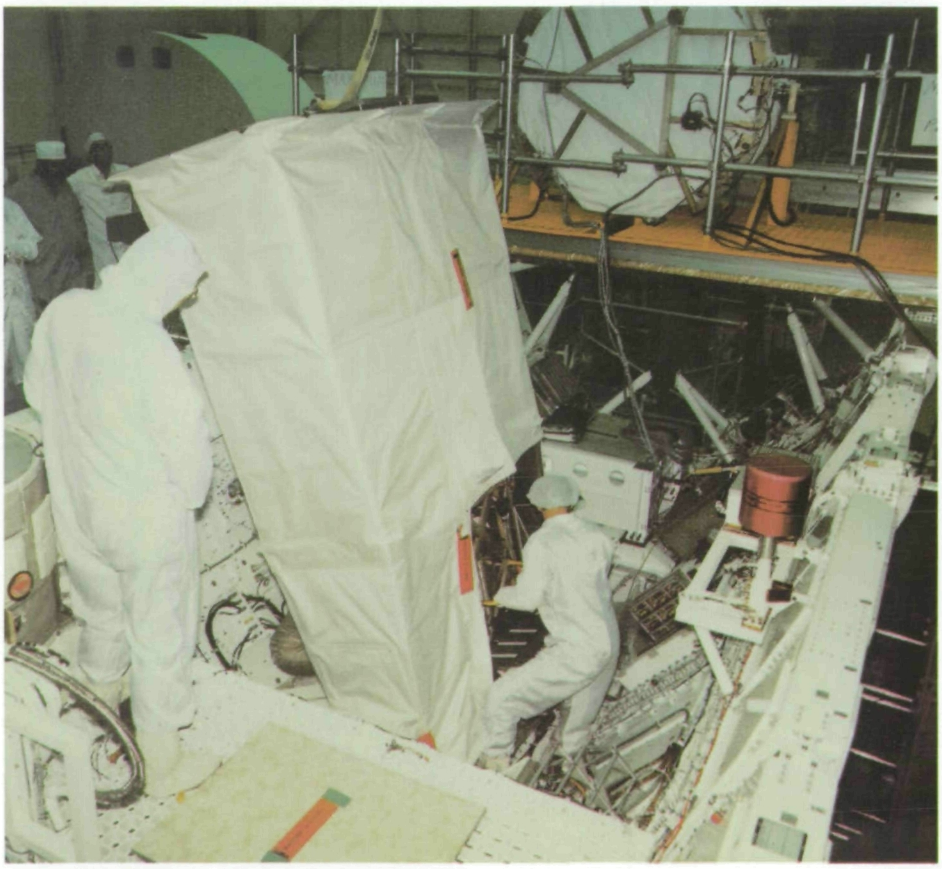
Hard X-Ray Imaging of Clusters of Galaxies and Other Extended X-Ray Sources

X-Ray Telescope (XRT)

Dr. A. Peter Willmore
University of Birmingham
Birmingham, England

Purpose: The goal of this investigation is to image and examine the X-ray emissions from clusters of galaxies in order to study the mechanisms that cause high-temperature emissions and to determine the weight of galactic clusters.

Importance: Objects throughout the universe emit X-rays, which are evidence of violent events at very high temperatures. Like stars, most X-ray sources appear point-like, but some X-ray emissions are more variable, sometimes released in sudden, intense bursts.



The large X-Ray Telescope is mounted on the second Spacelab 2 pallet.

Some X-ray sources are "extended" diffuse sources rather than point sources. The most extended X-ray sources are enormous clusters of galaxies, containing anywhere from a few to several hundreds or thousands of galaxies. A single cluster can extend for millions of light years. (One light year is about 10 trillion kilometers or 6 trillion miles.)

Galaxy clusters are a major astrophysical puzzle. By studying the motions of the galaxies in a cluster, astrophysicists can deduce a cluster's mass, but the calculated total is always much greater (about 10 to 100 times greater) than the mass which can be detected in the form of stars, dust, and gas inside the galaxies. There seems to be some invisible matter present. Some of this missing mass was identified when it was discovered that galaxy clusters emit X-rays, which arise from extremely hot gas (100,000,000° C) filling the space between galaxies. The mass of the intergalactic gas in a cluster is roughly equal to that of all the galaxies in that cluster, but the total observed mass is still less than the predicted total.

Where is the missing mass, and what form does it take? There are many possibilities: black holes (collapsed stars with strong gravitational force that draw in matter); many dim, low mass stars; or a sea of invisible particles such as massive neutrinos. Since the hot X-ray emitting gas is kept in place by the gravitational attraction of all the matter in the galaxy cluster, a detailed study of the brightness and spectrum of the X-rays across a cluster should reveal how much mass there is and where it is situated. The X-ray telescope on Spacelab 2 is the first instrument capable of making this detailed survey.

Although the X-rays from some galaxy clusters probably originate in gas of a fairly constant temperature, the X-ray spectrum in many cases shows the situation to be more complex. In some clusters, gas is cooling and flowing into giant galaxies at the cluster's center. In other cases, disturbed galaxies within a cluster probably account for part of the X-ray emission. The X-ray telescope clarifies what is happening in such complicated cases by showing how the emission varies from one part of the cluster to another.

The Spacelab 2 telescope also has the opportunity to study X-ray sources other than clusters of galaxies. The telescope is designed to be refurbished and reflown many times, so a large data base on extended galactic X-ray sources can be accumulated.

Method: A novel but proven technique is used to produce high-energy X-ray images of a small region of the sky. The spatial (direction) and spectral (wavelength) distributions of X-ray emission in the 2 to 20 thousand electron volt (KeV) range are detected with two telescopes observing at different resolutions. One telescope detects faint, extended regions of X-ray emission with a coarse resolution of 12 x 12 arc minutes, and the other resolves details in intense X-ray regions with a

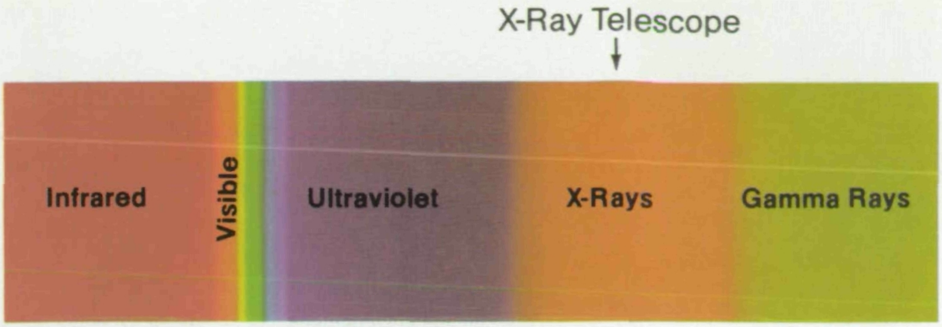
fine resolution of 3 x 3 arc minutes. This dual system allows both the bright central regions of galaxy clusters and their more diffuse out-lying parts to be studied.

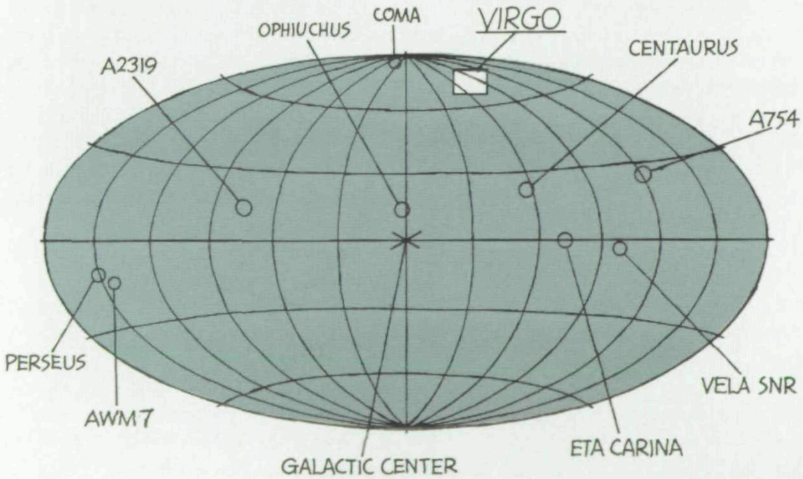
Unlike visible light, X-rays are absorbed by objects rather than reflected. Thus, unlike optical telescopes using conventional mirror systems, X-ray telescopes must use other methods to focus incoming radiation. Both Spacelab 2 telescopes use a coded X-ray absorbing binary mask and a position-sensitive multiwire proportional detector from which X-ray images can be created. The mask, dotted with small holes in random locations, produces a shadowgram on the detector as the telescope is exposed to X-rays. The detector determines the energy and position of arrival of each X-ray photon.

Patterns created by the mask can be decoded by a computer on the ground to make X-ray images of source objects. By studying these images, scientists can tell how large and bright the X-ray sources are. They can also measure the energies of the X-rays emitted by different parts of the source, and they can distinguish between continuous emitters and those that blink on and off. The images collected during the mission can be used to produce an atlas of extended (diffuse) X-ray sources.

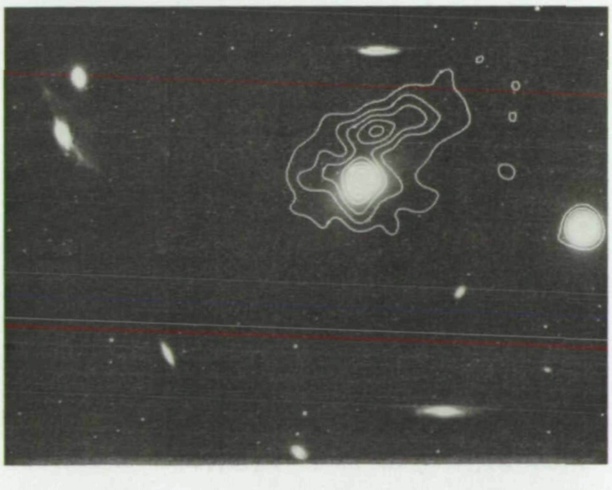
To gather enough data about those sources located many millions of light years away, the telescope observes each target for several hours. A microprocessor system gets attitude information from the Shuttle data system, selects accessible targets from preprogrammed lists, and commands the telescope's own pointing system to orient the instrument. Then, a motorized two-axis gimbal system steers the double telescope to the required orientation. Star trackers and gyros continuously pinpoint the precise direction of the telescopes. The large instrument is mounted alone on the second pallet in the Shuttle payload bay.

Co-investigators for this experiment are Dr. Christopher J. Eyles, Dr. Philip K.S. Harper, Dr. John R.H. Herring, Dr. Trevor J. Ponman, Mr. James C.M. Peden, Dr. Andrew M.T. Pollock, and Dr. Gerald K. Skinner, all of the University of Birmingham.

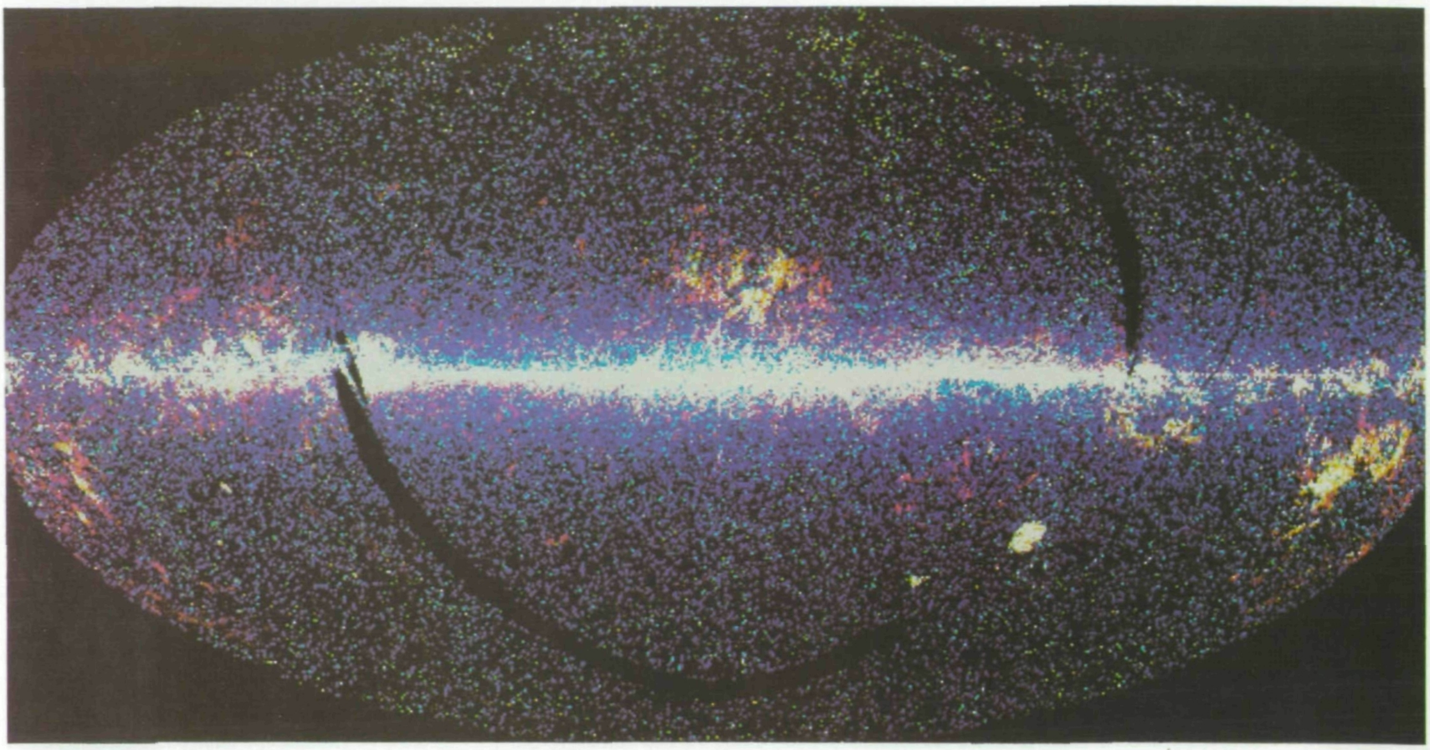




Celestial map, showing the X-Ray Telescope's observation targets



The X-ray contours of the Virgo cluster, obtained by the HEAO-2 satellite, are superimposed on a visible light photo of the same area. X-ray emission is concentrated around two bright galaxies in the cluster and appears between the galaxies as well. The Spacelab 2 X-Ray Telescope makes similar observations at higher energies.



More than 250,000 point sources are shown in this projection of the entire sky, assembled from data collected by the Infrared Astronomical Satellite (IRAS). The plane of the Milky Way runs horizontally across the middle. The image is color-coded so that the warmest material is blue, the next-warmest is green, and the coolest material is red. Solid black areas are regions that were not scanned by IRAS.

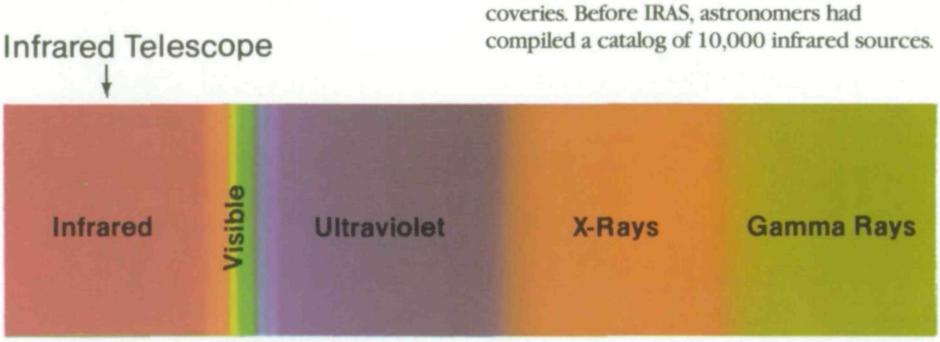
Infrared Astronomy

As the X-ray telescopes observe extremely hot celestial objects emitting short-wave radiation, an infrared telescope observes cool objects emitting radiation at longer wavelengths. Almost everything radiates invisibly in infrared. When an object is not quite hot enough to shine in visible light, it emits the bulk of its energy at infrared wavelengths. Fortunately, infrared wavelengths are so long that the light photons pass through the interstellar dust that obscures many of our observations at other wavelengths. Thus, infrared astronomy is an excellent way to detect cool objects, such as planets, cool stars, prestellar clouds, and galaxies, as well as the background radiation from the expanding universe.

Recently, the Infrared Astronomical Satellite (IRAS, 1983-84) made many exciting discoveries. Before IRAS, astronomers had compiled a catalog of 10,000 infrared sources. During a first analysis of IRAS data, some 250,000 new sources were detected, and an equal number may yet be identified as detailed data analysis continues. Among the major discoveries are rings of dust in the solar system, new comets, possible embryonic solar systems around other stars, new star-forming regions and uncharted galaxies, a new view of the center of the Milky Way, and mysterious objects at the edge of the universe. By the time IRAS expended its coolant and ended its observations, it had made four complete surveys of 95 percent of the sky.

The vacuum of space is ideal for infrared observations. There are some "windows" in the atmosphere through which infrared radiation can enter, but water vapor and other gases in the atmosphere absorb much of the radiation. Furthermore, all warm objects around us, including the atmosphere, emit infrared radiation, which overwhelms the fainter astronomical emissions. Looking at celestial objects in the infrared sky from the ground at night is like trying to see visible stars in the daytime.

From Spacelab 2, most of this background radiation is eliminated, permitting a clear view of the universe. The Spacelab 2 infrared telescope can take a second look at some of the IRAS discoveries, fill gaps in the IRAS data, and add to the growing list of infrared sources. It will also extend our knowledge of the infrared sky to shorter wavelengths. This instrument is designed to look at strong, compact (discrete) sources (as IRAS did) and at weaker, diffuse (extended) sources millions of light years away from Earth. The telescope surveys the sky several times, and the resulting maps should add to our understanding of infrared radiation in our galaxy and the universe.



A Small Helium-Cooled Infrared Telescope (IRT)

Dr. Giovanni G. Fazio
Smithsonian Astrophysical Observatory
Cambridge, Massachusetts

Purpose: The objective of this investigation is to measure and map diffuse and discrete infrared astronomical sources while evaluating the Space Shuttle as a platform for infrared astronomy. At the same time, a new, large superfluid helium dewar system for cooling the telescope is evaluated.

Importance: Astronomers are just beginning to explore the universe in the infrared region of the spectrum. Infrared radiation has a distinct advantage over radiation at the shorter wavelengths of visible, ultraviolet, and X-ray radiation: it can pass through regions of space that would absorb the shorter wavelengths. Thus, infrared radiation reveals much of the dust and gas throughout our galaxy and others as well as distant, cool objects not observable in other wavelengths.

The Spacelab 2 infrared telescope is designed to make several specific types of observations. One of the most important tasks is to measure the diffuse infrared radiation from our galaxy, much of which is thought to be emitted by galactic dust. This dust may have been present since the origin of the universe or it may be created by exploding stars. Scientists are interested in the distribution, quantity, and temperature of these micron-sized dust particles that are smaller than dust particles in the air. Once the quantity and distribution of this dust is determined, new pictures of the distribution of matter inside our galaxy and others can be constructed.

Stars are often born inside dust clouds, but their appearance and growth cannot be seen because dust blocks our view in visible light. Dust also may be an indication that planets are forming around other stars. Infrared radiation can penetrate some of the dust and allow us to see deeper inside the clouds. From Earth's location in a spiral arm near the edge of our galaxy, we can see only one-third of the way to the galactic center in visible light, but in infrared we can see to the center of the Milky Way and beyond.

The telescope also measures zodiacal dust scattered across the plane of the planets in our solar system. Because this dust contributes background radiation to astronomical measurements, it must be distinguished from other sources for accurate measurements.

To complement IRAS observations, the Spacelab 2 telescope fills the gap in previous infrared sky coverage, extends coverage to shorter wavelengths, and observes the solar system in the direction away from the sun. The Spacelab 2 telescope also looks for long-term variability in infrared sources, calibrates bright infrared sources, and provides an absolute calibration for IRAS data.

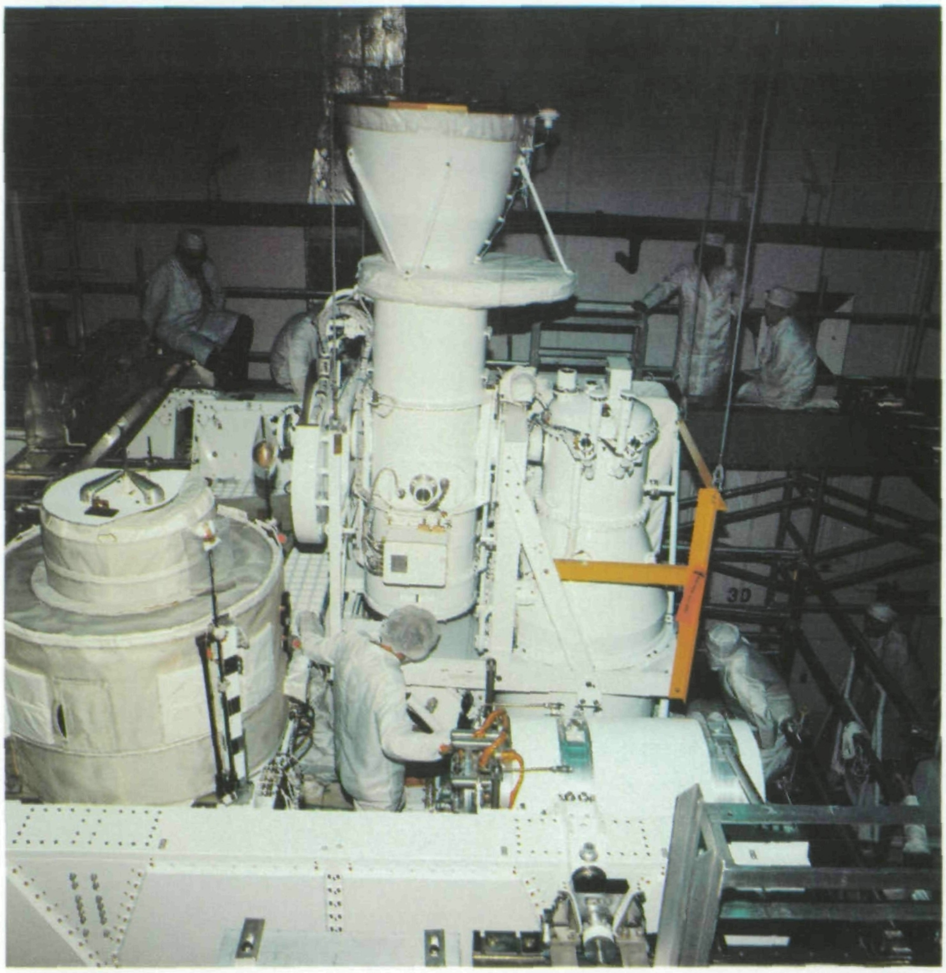
Finally, by making overlapping maps of broad areas, the Spacelab 2 telescope can distinguish between emissions from diffuse infrared sources and from discrete sources. Measurements of discrete sources will explain further how infrared sources are distributed throughout the universe. This telescope permits a large-scale study that will clarify the new map of the infrared sky.

Method: The 900-kilogram (2,000-pound) infrared telescope is located on the third Spacelab pallet. It is a Herschelian telescope, which uses a single 15-centimeter (6-inch) diameter mirror to focus the radiation onto detectors located to one side. The telescope is highly baffled to avoid exposure to natural and Shuttle-induced background radiation. The focal plane of the telescope has 9 detectors, covering the wavelength region from 4 to 120 microns (1 micron equals 10,000 Å) in 4 broad spectral bands and 1 narrow band. A tenth detector, operating in the range between 2 and 3 microns, is used for locating known stars. A drive motor moves the telescope at an angular speed of 6° per second and covers a 90° arc across the sky.

An infrared telescope must be cooled to keep its own thermal infrared radiation from overwhelming the infrared radiation from celestial sources it seeks to measure. The cryogenic system for cooling this telescope consists of a 250-liter (65-gallon) superfluid helium dewar. A porous plug is used to restrain the liquid helium and allow the flow of gaseous helium to cool the telescope. The effectiveness of this system is being evaluated as part of the experiment.

For the infrared sky survey, the nose of the orbiter is pointed forward with the open payload bay pointed away from Earth. The telescope scans over 90° of the sky in a plane perpendicular to the direction of orbiter motion. As the orbiter circles Earth every 90 minutes, the area being mapped changes so that

This dusty patch of sky around the constellations Taurus and Perseus is filled with young and embryonic stars. The image assembled from IRAS data is color-coded with the warmest material being blue, the next-warmest green, and the coolest red.



Technicians inspect the infrared telescope (left) and its superfluid helium dewar (right).

different regions of the sky are surveyed. The combined motion of the orbiter and the telescope permit each astronomical source to be detected at least twice during consecutive telescope scans and allows more than half the sky to be mapped in one orbit.

In 27 hours of observation during the Spacelab 2 mission, each part of the sky is seen about 14 times by each detector. This combination of immediate rescan with rapid all-sky coverage ensures enough redundancy in the data to be able to reject spurious signals and permit accurate identification of astronomical sources.

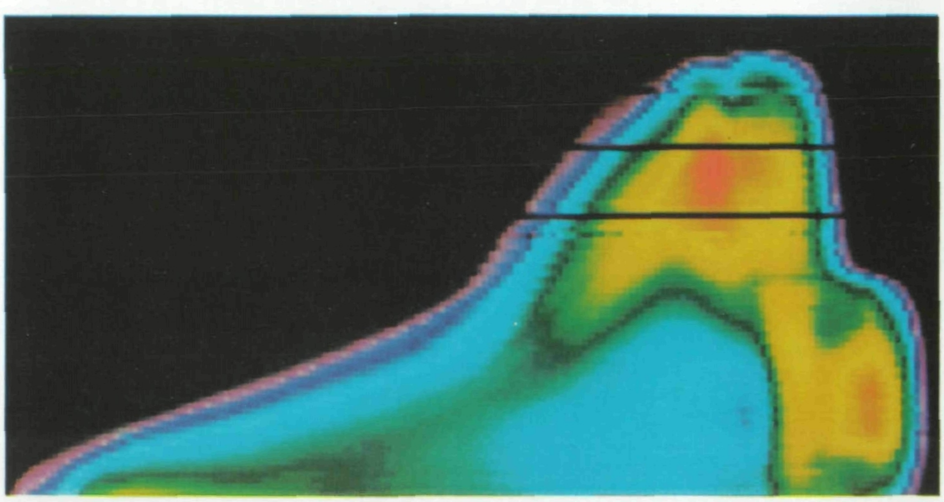
The sensitivity of the infrared detectors also allows an evaluation of the Shuttle environment for future astronomy experiments. Water vapor and other gases, in addition to dust particles from the Shuttle, emit infrared radiation and can confuse infrared measurements. During the data analysis, these elements will be evaluated to see if they emit enough infrared radiation to interfere with astronomical measurements.

An orange-red glow observed around the Shuttle during early missions is also studied by the infrared telescope. This glow has appeared above surfaces exposed to energetic collisions with particles, atoms, and molecules in the ambient space environment. The Spacelab 2 infrared telescope experiment presents a unique opportunity to measure, for the first time, the infrared spectrum of the glow. The infrared telescope and the Plasma Diagnostics Package (PDP) are used together to examine chemical reactions between the plasma environment and the Shuttle. The PDP, which has surfaces similar to the Shuttle's, is held near the infrared telescope for measurements of the type and quantity of constituents involved in glow reactions. The results of this experiment will contribute substantially to understanding the causes of the phenomenon, and they may be useful for the design of future space telescopes, such as the Space Infrared Telescope Facility and the Hubble Space Telescope.

Infrared telescope observations do not begin until two days into the mission, after orbiter dust and gases have dissipated. The experiment can be commanded from the Payload Operations Control Center or from the Spacelab aft flight deck.

Co-investigators for this experiment are Dr. William F. Hoffmann, Dr. Frank J. Low, and Dr. George Rieke, all of the Steward Observatory at the University of Arizona in Tucson, Arizona; Dr. Wesley A. Traub of the Smithsonian Astrophysical Observatory in Cambridge, Massachusetts; and the Spacelab 2 mission scientist, Dr. Eugene W. Urban of NASA/Marshall Space Flight Center in Huntsville, Alabama. IRT project scientist is Dr. David G. Koch of the Smithsonian Astrophysical Observatory.

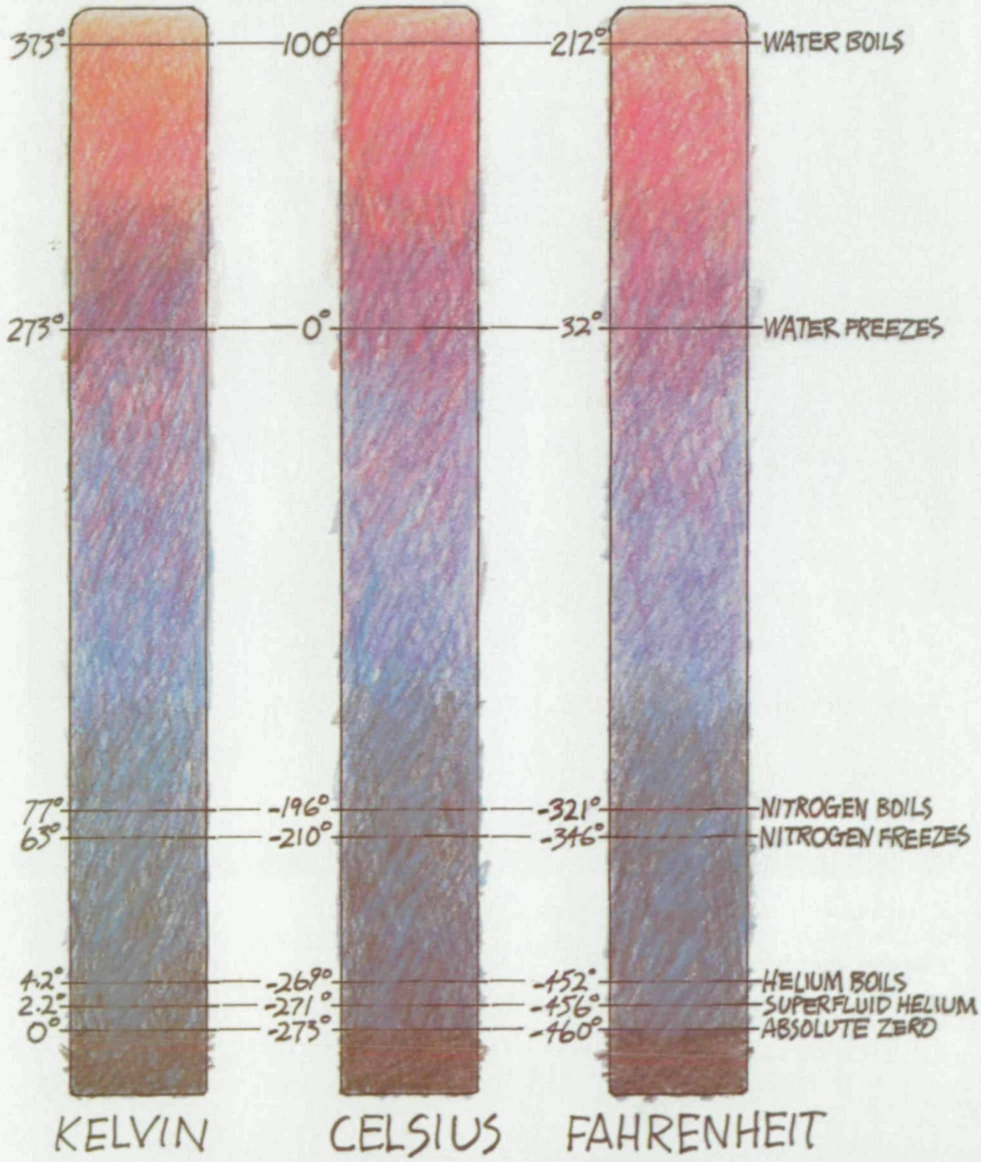
Almost everything radiates in the infrared, including the Space Shuttle Columbia. A computer image of the Shuttle's underside during descent is color-coded, with yellow and red indicating hotter areas and blue and green indicating cooler areas. (The purple bordering the image is a ghost created by image processing.) The image reveals how re-entry into the atmosphere heats the spacecraft's belly and wings.



Technology Research

Since the beginning of spaceflight 25 years ago, we have been inventing new materials and adapting equipment to work in the space environment. Spacelab 2 gives engineers a chance to study the characteristics of a potentially useful substance—superfluid helium—in space. Liquid helium, which exists only at temperatures within a few degrees of absolute zero and does not solidify, has two different states. The first state, helium existing in the temperature range of 4.2° to 2.2° Kelvin (−268.9° to −270.9° C), is difficult to contain in zero gravity. The second state, called superfluid helium, is colder than 2.2°K (−270.9° C/−455.6° F) and has several unique and interesting properties that permit containment in microgravity. Because it is colder than any other liquid, superfluid helium is being used as a cryogen to cool infrared telescopes, such as the one flying aboard Spacelab 2. These telescopes perform much better if they are cooled almost to absolute zero, the lowest temperature possible. Extremely low temperatures prevent instruments from radiating infrared energy that would interfere with their measurements of other infrared sources; such background "noise" would otherwise mask the fainter signals received from celestial objects. The use of superfluid helium in low gravity is still experimental, and scientists would like to gather better data on its behavior in the space environment.

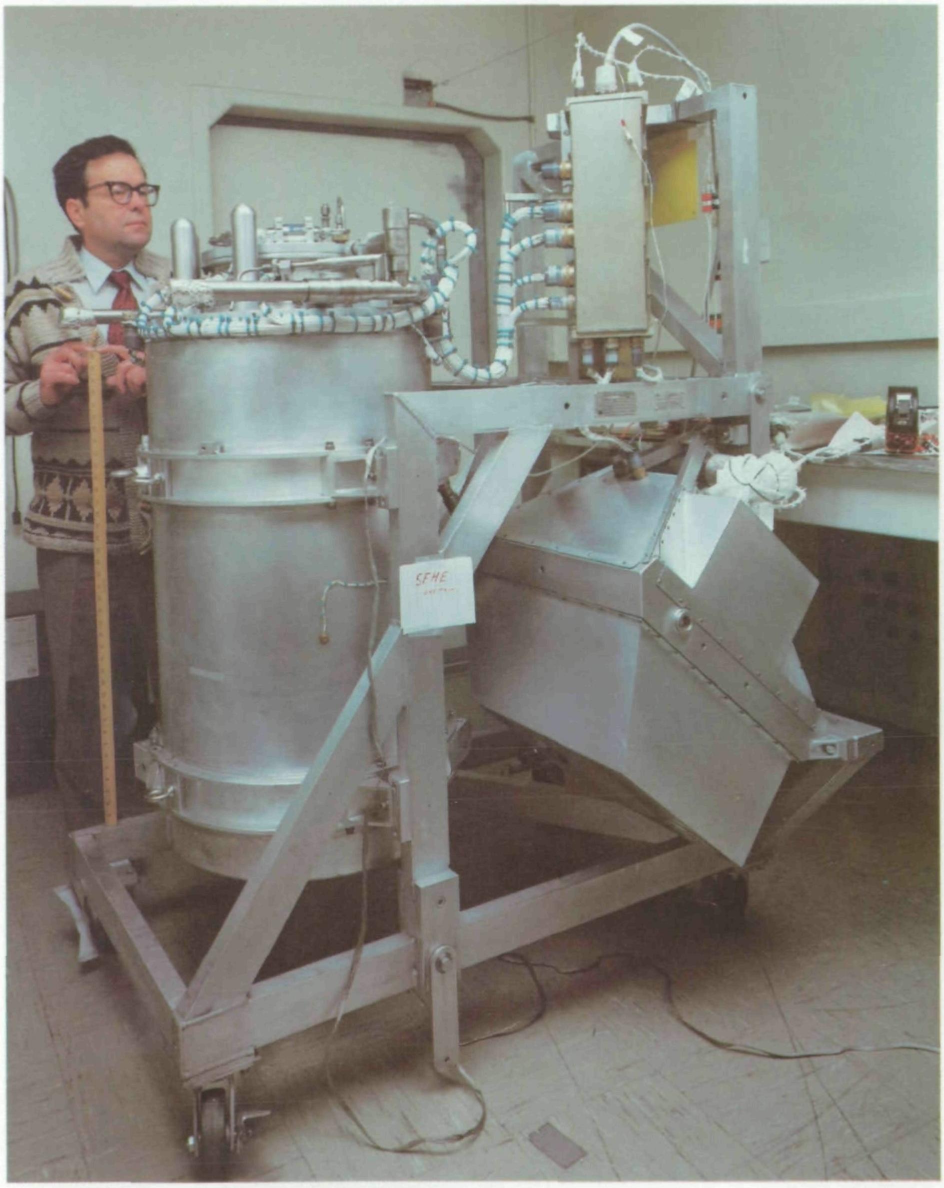
A large superfluid helium cryogenic system cools the Spacelab 2 infrared telescope. Another smaller superfluid helium dewar is attached to the third Spacelab pallet. Measurements from these dewar systems provide data on the performance of superfluid helium as a coolant in space and should influence the design of cryogenic systems for advanced infrared telescopes.



Properties of Superfluid Helium In Zero-Gravity

Dr. Peter V. Mason
Jet Propulsion Laboratory
Pasadena, California

Purpose: The objectives of this investigation are to determine the fluid and thermal properties of superfluid helium, to advance scientific understanding of the interactions between superfluid and normal liquid helium, and to demonstrate the use of superfluid helium as a cryogen in zero-gravity.



Co-investigator Dr. Dusan Petrac inspects the superfluid helium dewar before it is integrated with the Spacelab 2 pallet.

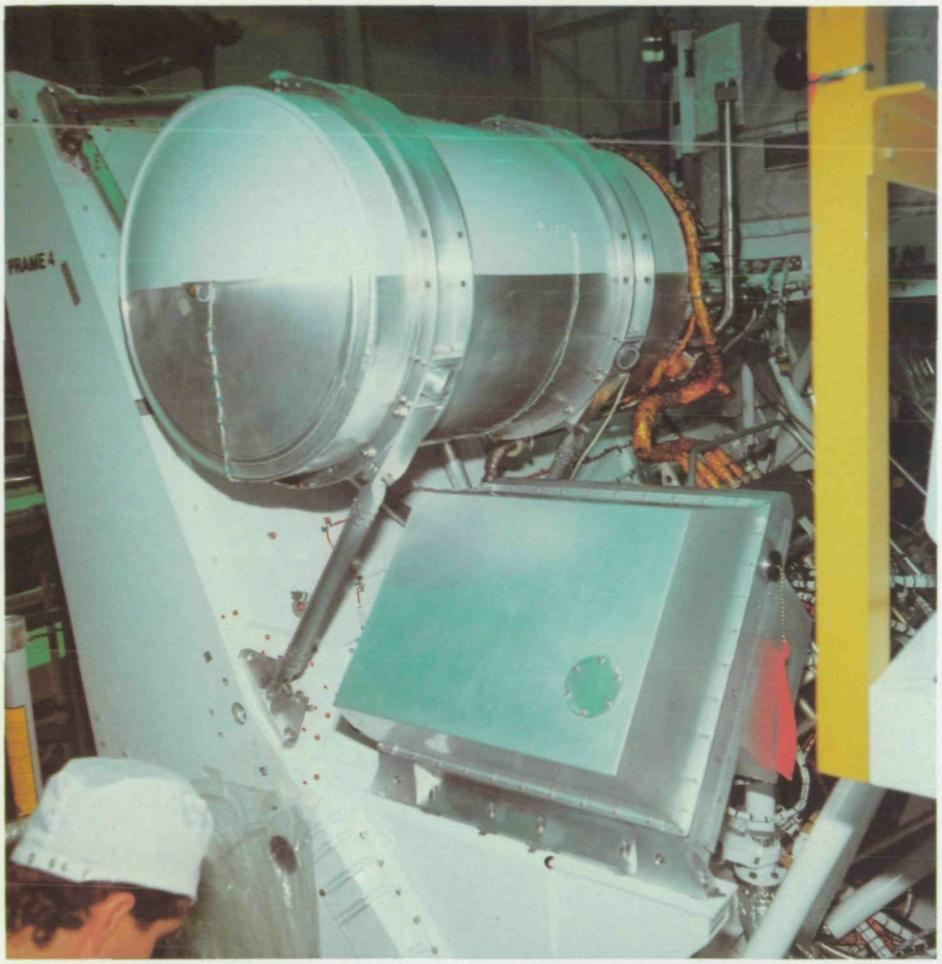
Importance: Liquid helium enters a completely new state of matter when its temperature is below $-270.9°$ C ($-455.6°$ F). This is within 2.2° C of absolute zero, the lowest possible temperature. In this superfluid state, helium has many unusual properties which have been the subject of intense study for more than 70 years. Superfluid helium can flow through extremely small pores that would block all other liquids, and it conducts heat about 1,000 times more efficiently than copper, the next best thermal conductor. It also can sustain five different kinds of sound waves, compared to one in normal fluids.

These traits make superfluid helium uniquely suited for cooling space instruments, such as the telescope on the Infrared Astronomical Satellite (IRAS), the Small Infrared Telescope aboard Spacelab 2, and the Space Infrared Telescope Facility which will fly in the 1990's. These instruments must be cooled so that their own infrared radiation does not overwhelm that from the celestial objects being observed. Infrared telescopes must operate at temperatures near absolute zero; only liquid helium can provide such cooling. Furthermore, superfluid helium's efficient thermal conductivity allows it to cool a telescope uniformly.

Superfluid helium also exhibits a property called the "fountain pressure," which is essential to its use as a space cryogen. The fountain pressure develops when superfluid helium attempts to escape from the dewar through a fine porous plug mounted in the vent pipe. Evaporation cools the outside surface of the plug slightly and produces a pressure which holds the liquid superfluid helium inside the dewar, where it continues to cool the experiment. Thus, the helium gas can be released into space without loss of the liquid coolant.

Superfluid helium was used successfully as a cryogen during the IRAS mission, and its temperature remained uniform to a few thousandths of a degree Celsius. However, future instruments will need temperature stabilities of a few billionths of a degree Celsius. To design future cryogenic systems, scientists and engineers need to know precisely how superfluid helium behaves under different conditions in microgravity. They are particularly interested in its movement patterns and temperature fluctuations.

Many of superfluid helium's traits are masked by Earth's strong gravitational force and, therefore, are observable only in space. This Spacelab 2 experiment gives scientists an opportunity to investigate the detailed behavior of superfluid helium in the microgravity environment. One important investigation, the quantized surface wave experiment, focuses on superfluid helium's ability to sustain sound waves on thin surface films. The tiny surface waves that physicists will study during this experiment are observable only in microgravity; on Earth they are overwhelmed by larger gravity-related waves. By studying the behavior of these surface waves, scientists hope to better understand the properties of superfluid



The barrel-shaped superfluid helium dewar is mounted on the third pallet.

helium. Data from the superfluid helium investigations will be used in preparing more efficient cryogenic systems for space instruments of the future.

Method: The main dewar is an insulated container filled with 100 liters (26 gallons) of superfluid helium. Throughout the mission, a variety of sensors inside the container monitor the helium's properties. Very precise sensors measure the temperatures of the dewar, the porous plug, and the insulation.

Within the dewar are two smaller vessels, each containing a fluid physics experiment. One is a 3-liter (0.78 gallon) vessel that is partially filled with liquid helium and contains an open-frame structure. On the structure, 133 liquid-vapor phase sensors measure the location of the superfluid helium. Twelve semiconductor sensors measure temperature variations throughout the liquid and temperature fluctuations induced by Shuttle motions. From these measurements, scientists can determine whether fluid motions affect sensitive experiment systems and whether temperature fluctuations cause an uneven distribution of coolant.

Inside the second vessel, another experiment investigates the velocity of capillary waves, very weak sound waves, on the surface of thin superfluid helium films. Five ring-shaped tracks contain sufficient helium to form films between 0.5 and 2 micrometers (0.2 to 1 microinch) thick. Small heat pulses generate the waves which travel around the tracks. Sensors measure the wave arrival times and amplitudes from which velocities and attenuations can be derived. From the analysis of this information, the physics of the wave process can be determined.

To be successful, the experiment must be conducted with the smallest possible mechanical disturbances. To reduce Shuttle motions during the experiment, the Shuttle is placed in a gravity gradient attitude with the tail of the orbiter pointing toward Earth. In this attitude, the orbiter is stable and there is no need for thruster firings to maintain attitude. Thruster firings could cause additional waves in the superfluid helium that would mask the more subtle waves being studied. Crew activity is also minimized while the experiment is operating.

A support electronics package transmits data directly to the ground, enabling investigators in the control center to monitor superfluid helium parameters throughout the mission. Measurements can be compared to those from the cryogenic system used by the Spacelab 2 infrared telescope.

Co-investigators for this experiment are Dr. Donald J. Collins, Dr. Daniel D. Elleman, Dr. Dusan Petrac and Dr. Taylor Wang, all of the Jet Propulsion Laboratory.

Life Sciences

While instruments on the pallets in the payload bay observe the universe, biological experiments are performed in the Shuttle middeck. Studying life processes in a microgravity environment can shed new light on the functioning of biological systems on Earth. These investigations can also help us understand how living organisms react to prolonged weightlessness.

One Spacelab 2 investigation studies how biochemical agents modulate and control body functions. Previous space crews have exhibited a pattern of bone mineral loss, particularly of calcium, phosphorus, and nitrogen. Although this loss has not affected the crew members' health, the bone mineral loss resembles that experienced by physically inactive people on Earth. By studying what metabolic changes accompany mineral loss in astronauts, scientists may be able to understand how these biochemical processes affect various body functions.

Plants also exhibit different behavior away from the influence of gravity. Lignin is a polymer found in many plants that gives them the strength and rigidity to stand upright in a terrestrial environment against the downward pull of gravity. The synthesis of lignin uses considerable metabolic energy; once formed, lignin is difficult to digest and interferes with the usability of industrially important cellulose in plants. While some lignin is necessary for normal plant growth, it may be possible to reduce its formation in plants where lignin interferes with the intended use. By growing seedlings in space where reduced lignin synthesis is expected, scientists hope to understand better how lignin production is controlled.

A crew member reports temperatures on the plant growth unit control panel to scientists on the ground during the third Shuttle mission.

Vitamin D Metabolites and Bone Demineralization

Dr. Heinrich K. Schnoes
University of Wisconsin
Madison, Wisconsin

Purpose: This investigation measures the vitamin D metabolite levels of crew members to gain information on the causes of bone demineralization and mineral imbalances that occur during prolonged spaceflight as well as on Earth.

Importance: Vitamin D is inactive until the liver and kidneys convert it into metabolites that are transported to various sites in the body. The chemical structure of the vitamin D metabolites was defined about 1970. Scientists are now exploring the multiple roles of these hormones in the functioning of the human body. Research into the biochemical nature of vitamin D has shown that the D-metabolites play a major role in regulating the body's calcium and phosphorus levels. One major function of the most biologically active vitamin D metabolite is to regulate the amount of calcium absorbed from the diet and taken out of the bone.

Since calcium and phosphorus are required by almost every system in the body, their levels in the blood are strictly controlled. The most biologically active vitamin D metabolite is actually a hormone which balances these minerals. Changes in blood mineral levels can create problems throughout the entire body. For example, calcium gives bones rigidity and strength and is necessary for muscle contraction, blood clotting, nerve transmission, and many other body functions. Investigators know that too much of the calcium-regulating vitamin D metabolite can result in less bone and excess calcium in the blood, which can adversely affect all calcium-related body systems. Too little of this metabolite can result in inadequate calcium in the blood and bone disorders such as rickets or osteomalacia.

Increases in blood calcium and phosphorus along with decreases in bone mass were observed in crew members of the Skylab missions. Although these alterations were not sufficient to affect astronaut health, they resemble bone mineral losses occurring in bedridden patients and patients being treated for vitamin deficiencies and bone mineral loss on Earth. These losses appear to be related to the amount of time spent in space; the longer the flight, the greater the mineral loss. Since vitamin D is a primary regulator of calcium and phosphorus, researchers would like to know its role in the bone and blood mineral alterations noted in space travellers.

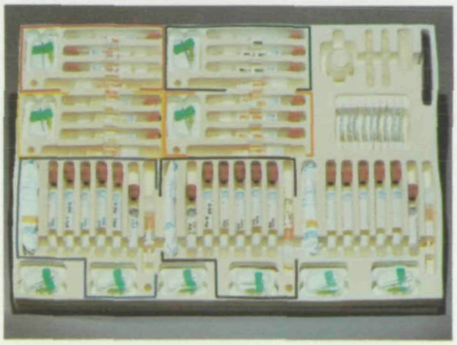
Research into the chemical structure of the D-metabolites has led to reliable and routine methods of measuring them. Other blood components are first extracted, and then the D-compounds are separated according to their chemical structures. The D-metabolites are present in blood in such small amounts that an extremely sensitive final assay is then necessary. As a part of this Spacelab 2 investigation, new techniques were refined on the ground, and now less blood is needed to analyze the D-metabolites. These new methods are being used in ongoing research into the importance of the vitamin D metabolites in regulating calcium and phosphorus dependent body functions.

Crew members drew blood during the Spacelab 1 mission. Spacelab 2 crew members perform similar blood draws as scientists continue to examine how the body functions in weightlessness.

Method: This investigation has two phases, a developmental phase and a final phase. The developmental phase includes extensive testing before flight, and the final phase involves the postflight analysis of the crew's blood samples.

Before any blood samples were taken from the crew, investigators studied samples from both animals and humans to increase their knowledge of the blood levels in different groups and to devise new and better methods for metabolite analysis. Rats, chickens, and monkeys were maintained on different diets so that researchers could study how the body changed with different vitamin D levels. Other animals lived in an environment of simulated weightlessness, which allowed researchers to study the relationship between inactivity and vitamin D. In addition, blood samples from normal, bedrested, and diseased patients, particularly those with bone-related problems, were analyzed. The results of the testing helped investigators choose the best methods to use for analysis of Spacelab results and gave them a broad range of data for comparative analysis.

In flight, 25 milliliters (0.75 ounces) of blood are taken from each of the crew members both early and late in the mission. A



A standard NASA life sciences blood kit is used for the Spacelab 2 bone demineralization experiment.

standard life sciences blood collection kit is used by the crew members to draw blood from each other. The blood samples are placed in a centrifuge to separate the plasma from the blood cells, and the plasma is stored in a freezer for the rest of the flight. All equipment is stored in a middeck locker. In the final phase, upon return to Earth, the frozen plasma is analyzed for D-metabolite levels and compared to samples of plasma taken from crew members before flight.

The co-investigators for this experiment are Dr. Hector F. DeLuca of the University of Wisconsin, and Dr. Emily M. Holton of the NASA/Ames Research Center in Moffett Field, California. The project scientist is Dr. Nitza Cintron of the NASA/Johnson Space Center in Houston, Texas.

Gravity-Influenced Lignification In Higher Plants

Plant Growth Unit (PGU)

Dr. Joe R. Cowles
University of Houston
Houston, Texas

Purpose: The purpose of this investigation is to determine the effects of microgravity upon the production of lignin in higher plants.

Importance: Lignin is a structural polymer that binds plant cells together and provides them with the rigidity to grow upward against gravity. While lignin is a useful structural compound, it is not always desirable. We cannot digest lignin so it reduces the use of certain plants as food. Lignin also interferes with the direct usability of plant cellulose for some industrial products, such as paper.

As lignin is created in plants, it uses considerable energy derived from photosynthesis. If less energy were used for lignification, then more energy would be available for the synthesis of digestible plant compounds such as proteins, lipids, and carbohydrates. The ability to control lignin formation could lead to more nutritious food products as well as more accessible industrial compounds.

The Shuttle-Spacelab is an excellent laboratory in which to test hypotheses concerning the effect of gravity upon lignification and to study the effect of microgravity upon plant growth and development. A similar experiment to this one was performed during the third Shuttle mission. Mung beans, oats and pine seedlings were grown in a plant growth unit (PGU). During post-flight analysis, scientists determined that the space-grown mung beans had 15-22 percent less lignin than a control group of mung beans grown on the ground. The space-grown oat and pine seedlings showed only a slight, insignificant reduction in lignin. Clearly, further studies are needed to determine precisely how gravity affects lignin production.

Mung beans (above) and pine seedlings (right) grown in space during the third Shuttle mission have slightly different characteristics than their Earth-grown counterparts. For example, without a gravity cue some mung bean roots grow upward in space.

Method: Young plant seedlings are grown in enclosed chambers resembling terrariums. These growth chambers are inside two plant growth units, which have their own lighting, thermal control, power, and instrumentation.

Mung beans are planted in four chambers and pine seedlings are planted in eight chambers just before launch. The mung beans are planted just prior to launch so that they germinate in space. Half of the pine seedlings are four days old, as were the pine seedlings flown previously, and half are ten days old. Investigators are growing the ten-day-old seedlings to see if lignin reduction is greater in the older plants than in the younger ones.

The growth chambers are sealed and the atmosphere of each chamber is exchanged with gas mixtures containing known amounts of oxygen and carbon dioxide. Shortly before launch, the chambers are loaded into the plant growth units, transported to the launch pad, and installed in locker spaces in the Shuttle middeck.

During flight, temperature and lamp status data are monitored from a control panel. Three times a day, crew members check the temperatures inside the growth chambers. The crew also take gas samples and photograph the plants twice during the mission.

Within an hour after Shuttle landing, the plant growth units are returned to a ground-based laboratory. Each chamber's atmosphere is sampled for metabolic gas content. The seedlings are photographed and measured, and subsequently they are sectioned and analyzed for lignin content and related enzyme activities.

After the analysis, an identical group of plants will be grown on the ground as controls. Temperature profiles obtained on orbit will be recreated for a temperature environment similar to the one experienced by the flight plants. The lignin content and other characteristics of the controls will then be compared with the Spacelab 2 specimens.

The project scientist for this experiment is Edward L. Merek of NASA/Ames Research Center in Moffett Field, California.

INVESTIGATIONS SUMMARY

DISCIPLINE	Exp. Number	TITLE	PRINCIPAL INVESTIGATOR
Solar Physics	8	Solar Magnetic & Velocity Field Measurement System (SOUP)	Dr. Alan Title (Lockheed Solar Observatory)
	9	Coronal Helium Abundance Spacelab Experiment (CHASE)	Prof. J. Leonard Culhane (University College, London)
			Dr. Alan Gabriel (Rutherford Appleton Laboratory, England)
	10	Solar Ultraviolet High Resolution Telescope & Spectrograph (HRTS)	Dr. Guenter Brueckner (Naval Research Laboratory)
Atmospheric Physics	11	Solar Ultraviolet Spectral Irradiance Monitor (SUSIM)	Dr. Guenter Brueckner (Naval Research Laboratory)
Plasma Physics	3	Ejectable Plasma Diagnostics Package (PDP)	Dr. Louis Frank (University of Iowa)
	14	Vehicle Charging and Potential Experiment (VCAP)	Dr. Peter Banks (Stanford University)
	4	Plasma Depletion Experiments for Ionospheric and Radio Astronomical Studies	Dr. Paul Bernhardt (Los Alamos National Laboratory)
			Dr. Michael Mendillo (Boston University)
High Energy Astrophysics	6	Elemental Composition and Energy Spectra of Cosmic Ray Nuclei (CRNE)	Dr. Peter Meyer Dr. Dietrich Müller (University of Chicago)
	7	Hard X-Ray Imaging of Clusters of Galaxies and Other Extended X-Ray Sources (XRT)	Dr. A. Peter Willmore (University of Birmingham, England)
Infrared Astronomy	5	A Small Helium-Cooled Infrared Telescope (IRT)	Dr. Giovanni G. Fazio (Smithsonian Astrophysical Observatory)
Technology Research	13	Properties of Superfluid Helium in Zero-Gravity	Dr. Peter V. Mason (Jet Propulsion Laboratory)
Life Sciences	1	Vitamin D Metabolites and Bone Demineralization	Dr. Heinrich K. Schnoes (University of Wisconsin)
	2	Gravity-Influenced Lignification in Higher Plants	Dr. Joe R. Cowles (University of Houston)

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